An Investigation into the Applications of Database Techniques to the Quality Assurance of Manufacture

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by

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Abstract

The basic concept for this work is that, in a Total Quality environment, all data must be considered to be quality data in order to achieve a truly informed process of continuous quality improvement, throughout the whole range of organisational activity.

In order to establish the place of this concept in respect of current theory, a number of quality control, quality assurance and Total Quality techniques and strategies are examined. In each case, an attempt is made to define the data support necessary to ensure the best possible effectiveness in use. In some instances, IT tools are already available; their applicability is investigated and their limitations are established, with a view to future integration.

Another issue which must be considered is the location of existing quality data throughout the many systems (both computerised and paper-based) which support the various areas of organisational activity. Of particular importance are the questions of which data is held, and how accessible it is for use in problem investigation and improvement planning.

The above surveys are drawn together to guide the construction of a set of aims and objectives to be satisfied by an Integrated Quality System (IQS). These were then formalised into a functional requirement for a generic IQS in line with current Total Quality theory. However, a theoretical system must, of necessity, be customised to suit the needs and working practices of real organisations. Hence, the findings of a study carried out at a manufacturing company by the members of the project team in which the author worked were used to establish user requirements for an IQS. The two sets of requirements, theoretical versus user, were then merged to provide a single, mutually satisfactory, functional requirement.

In order to investigate the appropriateness of various aspects of the proposed IQS, elements of the functional requirements were implemented in a laboratory prototype.

This prototype served a number of purposes:

a) to clarify the perceived desires of the test site users;

b) to investigate differences between various methods of eliciting software specifications (both functional and related to the mode of use) from users in terms of the final satisfaction achieved and the level of modification required during development;

c) to establish some of the interface links which must be provided to merge IT systems currently in use to achieve a truly integrated system for Total Quality

support;

d) to consider the importance of certain "poor relation" quality related activities in the light of integrated Total Quality.

The proposed IQS architecture is then revised in the light of the findings of the prototype and a modified structure is suggested. The recently published results of other researchers are considered and related to the modified IQS specification.

Finally, a programme for future work is described briefly.

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Glossary of Abbreviations

AQAP	Allied Quality Assurance Procedures
BS	British Standard
BSI	British Standards Institute
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
CAP	Corrective Action Procedure
CIM	Computer Integrated Manufacture
COC	Certificate of Conformance
CQDB	Central Quality Database
DBMS	Database Management System
ECMM	Equipment Calibration Monitoring Module
EN	European Standard
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode, Effect and Criticality Analysis
IQS	Integrated Quality System
IQSE	Integrated Quality Support Environment
ISO	International Standards Organisation
MIS	Management Information System
OODB	Object Oriented Database
QA	Quality Assurance
QC	Quality Control
QDAAS	Quality Data Acquisition and Analysis System

QIS	Quality Information System
RDBMS	Relational Database Management System
SPC	Statistical Process Control
SQL	Structured Query Language
TQM	Total Quality Management
TRM	Training Records Module
VMM	Vendor Monitoring Module
3GL	Third Generation Language
4GL	Fourth Generation Language

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Chapter 1

Overview

1.1 Introduction

Quality is a much misunderstood concept. Most people believe it is a measure of "excellence" (Hutchins [56], Sinha and Willborn [118]), so that a Rolls Royce is generally considered to be a "Quality" car whereas a Mini is just a car. Even within the professional quality fraternity there is disagreement as to how the concept should be defined. Crosby [20] states that quality is "Conformance to Requirements", whilst both Deming and Juran assert that simply doing a job "by the Book" (i.e. according to the specification or rules of the job) is not enough; quality must be associated with a constant striving to improve both "the Book" and the methods and tools used in the job. This interpretation of quality as not only meeting, but exceeding the customer's expectations is now widely accepted, as exemplified by Deming's identification of the customer as "the most important part of the production line" and statement that the product should be a delight to the customer: not merely to meet his expectations, but to exceed them.

This leads on to the reasons why quality is important in both manufacturing and service industry. According to Norton [94], the cost of quality (i.e. expenditure in respect of quality) may be divided between three well defined areas of activity; Prevention (5%), Appraisal (30%) and Failure (65%). Poor quality costs money in respect of scrap, rework, inspection, loss of custom through dissatisfaction and a variety of other less

obvious expenditures (a more comprehensive discussion of quality costs is given by Thoday [135] and Juran and Gryna [63] (section 5)). Traditionally quality has been viewed as a manufacturing issue, and therefore not of concern to those undertaking non-manufacturing activities (eg. clerical work). Hence the move towards Total Quality has forced acknowledgment that quality is as much an issue for non-manufacturing and manufacturing activities alike, and failures in either realm of activity can be equally costly. It may seem unnecessary to state that it is always cheaper to do or make something right first time, but this very message is at the core of almost all quality improvement programmes, and is often used as the means of convincing managers that such a programme is needed, hence Crosby's title "Quality is Free".

Thus we come to the question of how to achieve quality. In 1931, Shewhart [116] suggested the application of statistical control techniques. These techniques had been in use in science for some time, but had not previously been applied in manufacturing industry. It was this innovation which, for the first time, gave companies the ability to analyse quality problems (as identified by inspectors) and then take action to improve the operation of the process in the areas identified by the analysis. Thus quality control became a clearly recognisable discipline.

> *"Quality Control is the regulatory process through which we measure actual quality performance, compare it with standards, and act on the difference"* Juran and Gryna [63] (page 2-11)

In 1950, Dr W Edwards Deming was invited by the Japanese Union of Scientists and Engineers (JUSE) to present an eight day seminar on quality control. His methods of statistical quality control (which were closely based upon Shewhart's work) were adopted by the Japanese. However, it soon became evident that the usefulness of these methods was being undermined by lack of technical standards, combined with problems due to a lack of understanding and cooperation in the people involved with them (Bendell [7]). Despite these problems (which were addressed by Juran and Feigenbaum who focused more attention on the management issues of quality), the Japanese attribute the rebirth of their country's industry to Deming's work (Tiernan [136]). Deming himself later laid down 14 "Points for Management" as the basis for a transformation of American industry similar to that achieved in Japan.

Four years later, in 1954, Dr Joseph M Juran was also invited to address JUSE. His message placed much more emphasis on planning and management, and is the root of modern quality management. The core around which his work is built is the belief that quality does not happen by accident, it must be planned (Bendell [7]). This led to the development of Quality Assurance as a recognised discipline, utterly necessary in the process of quality improvement. Definitions of Quality Assurance reflect the need for planning combined with auditing to monitor progress so that the improvement process can be controlled, for example:-

> *"Quality Assurance is broadly the prevention of quality problems through planned and systematic activities (including documentation). These will*

include: the establishment of a good quality management system and the assessment of its adequacy, the audit of the operation of the system, and the review of the system itself." Oakland [96]

At about the same time, Armand V Feigenbaum originated the concept of "Total Quality Control".

"Total Quality control is an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of the various groups in an organisation so as to enable marketing, engineering, production, and service at the most economical levels which allow for full customer satisfaction." Feigenbaum [37]

This concept recognises that, while quality assurance activities addressing those processes directly concerned with product manufacture are vital, further benefits may be gained by widening the remit of quality assurance procedures to cover other activities (for example, sales and marketing, training or safety), so that the influence of activities peripheral to product manufacture, but none the less necessary to the operation of the organisation, may be clearly understood and measured. The idea being to understand the capabilities of all processes in the business with a view to building in quality at an early stage (Schonberger [115] (chapter 3)). As a result of this work, Feigenbaum too was invited to speak to JUSE.

The present high standard of Japanese manufacturing quality is directly attributable to the influence of these three "quality gurus". A discussion of the improvement of the Japanese quality image is given in Schonberger [115] (chapter 1). More details of the work of Deming and Juran can be found in Oakland [96].

More recently, Feigenbaum's concept of Total Quality Control has been expanded through Total Quality Assurance, into Total Quality Management. Under TQM the operation entire organisation is directed by focused management strategy and planning, which aims to achieve continuous improvement in all areas, through the proactive application of quality assurance techniques.

In referring to quality, a tacit assumption is often made that quality is an attribute of a product or service (Sinha and Willborn [118]). This is because quality is being judged from the customer's viewpoint, rather than the producer's. However, the real situation is not so simple; high quality products are, in fact, symptomatic of high quality processes and resources throughout the organisation which manufactures them (Hutchins [56]). Therefore, rather than focusing on the visible evidence of quality levels, i.e. the quality of the product, it is important that a quality assurance programme should take a holistic view to ensure that company-wide quality improvement measures are taken and have a real and lasting impact on the "quality health" of the organisation. It is worrying that both the literature and discussions which took place during the course of this work with staff from many different organisations suggest that those organisations actually putting this ideal into practice are still in the minority.

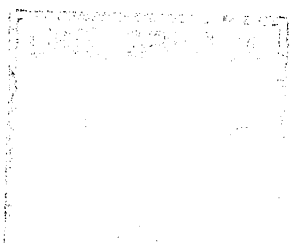
Quality assurance holds the key to the maximization of the long term profitability of an organisation because such profitability can only be achieved by the optimization of processes and resources with respect to market needs. A significant indicator of an organisation's quality health is profitability; a company which is not profitable, even though it has a good product, is not a "quality company" because it is not truly fit for its purpose.

In many companies, management and workers alike have been slow to recognise the importance of quality management in ensuring long-term company profitability. In some cases, quality is still viewed as an issue to be addressed by a policy of more and more inspection as a means of ensuring that the customer does not receive poor quality goods. Fortunately, an increasing number of companies have come to recognise that increased inspection can only lead to increased costs, without in any way addressing the root causes of product non-conformance. These companies have moved towards the monitoring and review of their manufacturing process in order to improve the process so that non-conforming products are not produced. Once the manufacturing process is brought under control by means of a quality assurance programme, the scope of that programme can be widened into Total Quality by the inclusion of other areas which contribute to product production. Information gained from process monitoring may then be used as an input to a company-wide quality improvement programme.

1.2 Company-Wide Quality Improvement Schemes

The management issues involved with the success of company-wide quality improvement schemes have been much investigated. The early work was carried out by Deming and Juran, who claimed that, since 85% of quality control problems are caused by imperfect systems or processes, not by the workers, it is therefore the responsibility of management to work on the system so that it is fit for the workers to work in. It is unclear who originated this idea, Tiernan [136] says it was Deming, Collard [17] and Tribus [137] that it was Juran, and Oakland [96] that Deming claimed 94% of problems required management intervention while Juran claimed about 80%. It matters not: the important point is that management should realise the extent of their responsibility in the process of quality improvement.

Of course, there is not total agreement between the approaches of the various quality gurus. For example, Deming categorically states "Eliminate slogans, exhortations and numerical targets" (point 10 of the 14 Points for Management), while Crosby strongly recommends the use of posters and slogans. An interesting paper by Kathawala [65] gives a comparative analysis of the basic ideas of Deming, Crosby, Juran and Feigenbaum, and concludes that "there is no all-encompassing correct solution". The following points however, are a synthesis of the principal management issues which have bearing upon the success of a company-wide quality improvement programme. They arise from the teachings of Deming, Juran, Feigenbaum and Crosby, but are well supported by case studies (Doran [31], Lloyd [80], Ogilvie [98], Payne [104] and Pateman [103]).



1.2.1 Management Commitment.

It is essential that top management fully understand and are committed to the programme. If this commitment is not in place the scheme will surely fail; either because the workers recognise that managers do not really mean what they say about quality improvement, or because the enthusiasm and commitment of the workers is destroyed by management's failure to act on improvement suggestions made by the workers. Doran [31] describes the process of attaining a uniform level of management conviction wherein the "painful transition of opening our minds to the possibility that others might be achieving better quality attitudes, approaches and results than our own" was undertaken.

According to Cullen and Hollingum [25] the single most important factor in the success of this improvement process is a firm and sustained commitment to Total Quality from the top of the organisation downwards.

1.2.2 Changing People's Attitudes

An important step in raising quality awareness is the movement from the view that since perfection is unattainable, failure is fore-ordained, to a recognition that most, if not all, failures are preventable when causes of failure are understood and taken into account in planning and carrying out work. The use of Acceptable Quality Levels (AQL) leads to the assumption that a certain proportion of defective items in the final product are inevitable. This tolerance of failure is firmly rejected by Japanese

manufacturers, who feel that they have a moral duty to their customer (and their company) to strive for quality improvement, regardless of economic considerations (Saha [113]).

A second attitude change which is necessary is in the way management view the workers and vice versa. This is exemplified by Collard's [17] examination of the "British Disease". It is important that managers realise that workers frequently know what is preventing them from achieving better quality, but are usually powerless to make the necessary changes. It is therefore essential that management listen to the workers and act upon the problems which they identify. Crosby [20] highlights the fact that managers often assume that, given the opportunity to report problems, workers will raise as many silly, time-wasting issues as they can, just to make life difficult for management. However, Crosby reports that companies that have committed themselves to this type of problem solving scheme have not had this experience, but on the contrary have found themselves deluged with helpful suggestions and clear problem statements. The other vital elements in this scenario are rapid response to the proposer, coupled with guaranteed investigation of every issue raised, for staff will soon stop reporting problems and making suggestions if they feel that their contributions are being ignored.

1.2.3 Quality Awareness and Training

All employees should be given training in why quality is important and what steps to take to improve quality in their own work. As employees absorb management

commitment to the identification and removal of factors which inhibit them from performing as well as they would like, there will be a demand for further training to allow the use of tools such as Quality Circles and Statistical Process Control (SPC). The scale of the necessary training programme should not be underestimated; Schonberger [115] (page 80) reports that the Japanese took an entire decade to train just upper and middle management, only then did they start training foremen and workers.

1.2.4 Recognition

It has been demonstrated that giving public recognition to staff who contribute to the quality improvement programme is a significant inducement to further commitment to the programme. It is important to realise that the type of recognition which is most appreciated is not necessarily monetary reward, but rather the conferring of an accolade in the presence of peers and superiors.

A further important point is made by Masing [85] who explains the "Pygmalion Effect" which expresses the, often unrealised, positive effects of letting subordinates know that you believe in their capability to undertake some specified task. There is, of course, a negative side to the Pygmalion effect; staff performance and motivation can be seriously undermined by supervisors who look down on them or belittle their efforts.

1.2.5 Time Scales

A major difference between a motivation programme and an on-going company-wide quality improvement scheme is the time scale involved. The life of a typical motivation programme is measured in months, whereas an effective quality improvement scheme takes a minimum of 1 year to get under way (Lloyd [80] quotes an implementation period of 4 years at Sony in Wales), followed by an active life which may (hopefully) be measured in decades, providing the company continues to stress the importance of the scheme. Crosby [20] emphasises the need for continuing work on the scheme (step 14: "Do it all over again") to ensure that it remains effective years after its introduction into the culture of an organisation

1.2.6 Benefits

The principal benefits reported by the various case studies referenced earlier are very similar. Unexpectedly high levels of staff interest led to wide-ranging improvement schemes which not only resulted in on-site quality improvement, but which worked their way back down the supplier chain to bring improvements in quality of in-coming goods (Pateman [103]). Higher levels of customer satisfaction were realised, resulting in an improved competitive position for the company. The benefits of improved quality are discussed by Smith [120] who gives many examples of companies for whom an attention to quality has resulted in great rewards.

Finally, there is a widely held view that improving quality costs money. In one sense

this is true; but such measures are highly dependent on how the bounds of the examination are drawn. A company-wide picture, however, demonstrates that, despite initial setting-up costs, successful quality improvement programmes yield great financial returns through decreases in those overheads associated with poor quality. Mortiboys [91] claims cost reductions of 5% to 10% of turnover, while Crosby [20] sets the possibilities even higher! Certainly there is evidence in a number of the case studies cited above that a large proportion of the process modifications made led to better process performance, which, coupled with major reductions in scrap levels and re-work, have produced significant reductions in production costs. One example is given by Payne [104] who reports that quality cost savings of £1,150,000 were achieved by Mullard Blackburn over the period 1982-86.

1.3 Quality Standards

Total quality and company-wide quality improvement schemes are approaches which may be used to better the quality health of an organisation, however it is necessary that a common language be established between customer and supplier to achieve mutual contractual satisfaction. To a large extent, this is why quality standards exist (Feilden [38]). Thus quality assurance systems arising from Total quality or quality improvement schemes must be designed to include the formal requirements of the various national and international standards to which the organisation may be required to conform (e.g. BS 5750/ISO 9000, AQAP). The British Standards Institution give the following definition:-

"Quality standards: The documents which define the agreed contractual, functional and technical requirements for all quality activities needed for a product, process, service or system to make it fit for its purpose."

Khan and Hashim [70] relate the evolution of quality standards from the making of a physical standard by a Babylonian potter through to the development of written standards by the UK and USA defence organisations who used them to achieve product interchangeability, lower manufacturing costs and reduced inventories.

1.4 The Impact of Modern Manufacturing Practices

The advent of new manufacturing methods and strategies (for example, increasing automation such as Flexible Manufacturing Systems (FMS) and Computer Integrated Manufacture (CIM) (Maull et al [87]), coupled with Just In Time manufacturing (Schonberger [115] (chapter 2) and Lubben [81]) and Ship To Stock policies) places new demands on a quality assurance system. There is now a need for highly capable processes which exhibit low variability, despite the complexity of the process. This complexity is frequently combined with high speed operation, so that many indicators of process performance must be monitored and analysed extremely rapidly to provide the necessary feedback of results to control the process (Veron et al [141]). Automation also leads to changes in the methods of monitoring which are appropriate in the context of the type of operation being undertaken and the speed of that operation (Wort and Tannock [150], Tannock and Hill [132]). Thus, in many of these new manufacturing situations, human intervention for inspection, analysis and corrective action is no longer

possible. These new strategies also highlight the need for increased confidence via improved cooperation and greater communication of quality data between supplier and customer, throughout the supplier chain.

As quality improvement programmes progress there is a greater need for exploratory analysis of historical quality data, which, when this data is held on paper, is prohibitively expensive, both in terms of resources and response time (Gribble [47]). Therefore, whilst satisfying the requirements of product liability laws and standards such as BS 5750, these records contribute little, if any, input to the process of continuous quality improvement in the organisation. Decision makers are thus deprived of much of the information which would be of use to them by the severe limitations inherent in paper-based data storage. These problems, combined with the new demands imposed by modern manufacturing practices, have precipitated a data handling crisis within traditionally paper-based quality assurance systems. Automatic process monitoring and control are vital in order to keep up with automated processes. Increasing product complexity requires much increased cooperation between customer and supplier in order to achieve satisfactory quality in the finished product (for example, custom silicon chips (TASIC [134])).

A solution to these constraints may be provided by the automation of the data handling facets of the quality assurance system. The information needs of decision makers fall into two distinct categories; firstly, generalised quality information about many processes, products or suppliers over extended time periods, along with the ability to

exercise demonstrable control over inspection specifications, equipment and records; secondly, detailed information pertaining to process control during the manufacturing process. The advantages of a computerised quality management information system are described by Sinha and Willborn [118] (chapter 16). It is the provision of the former category of information which this study addresses.

Chapter 2

Quality Techniques

2.1 Introduction

The hypothesis being investigated in this research is that there is a need for an integrated database spanning all sources of quality data within an organisation. The purpose of this system is the support of quality improvement activities in all functions throughout the organisation. It is further suggested that this information server should make use of existing systems wherever appropriate by acting as the integration mechanism to facilitate cross-system queries. Clearly, the design of such a facility must be based upon an understanding of the techniques employed in quality assurance and improvement, the influences of various management strategies, and the requirements of standards and the Law. It is the purpose of chapters 2, 3 and 4 to consider these matters and to examine the type of data processing support which is most appropriate for each. To this end, this chapter examines certain quality techniques with a view to establishing the type of data processing support is appropriate to each. The techniques considered below were identified (via discussions with a number of quality consultants and from a literature survey) as being of primary interest in the development of an effective quality system; as a result, details of other, less commonly used quality techniques which were investigated are not given herein but should be sought elsewhere (eg. in Juran and Gryna [63]).

2.2 Measurement and Understanding

The basis of quality improvement is measurement. Without measurement of some suitable quality indicator it is impossible to judge whether a process is improving or deteriorating. The selection of the quality indicator depends on both a knowledge of the process to be monitored, and on an understanding of how the customer of the process assesses the quality of items received from it. The primary objective is always to satisfy the customer. This may be achieved by improving the process in order to maximize customer satisfaction while making the process more efficient and less error-prone, thus minimizing the cost of giving full customer satisfaction. Thus it can be seen that thorough understanding of the process is fundamental to quality improvement, for measurement alone is useless unless it is combined with knowledge of what is being measured. Likewise, the determination of meaningful measures must be based upon understanding of the thing to be measured.

Achieving this understanding is one of the main stumbling blocks in the implementation of an effective quality improvement scheme. Where the process, or interactions between processes, are complex, it may be necessary to analyse and model the system. This task is a common one for the Systems Analyst, but may be a very daunting one for those outside that discipline, who are not familiar with the tools available to aid such analysis.

Many modelling methods are available, so often it is familiarity which is the main criterion for selection. However, in many quality improvement situations it is desirable

that the analysis be carried out by those involved with the process to be analysed, rather than by an outside specialist analyst. Thus any tools used must be quick to learn and easy to employ. This proviso precludes the use of many of the methods commonly used by Systems Analysts, for example, JSD/JSP (Jackson [59], King and Pardoe [71]), SSADM (Downs [32], MacDonald and May [83], Williams [146], Kutesko [75]), the Yourdon method (DeMarco [29], Page-Jones [101], Ward and Mellor [143]), or Structured Systems Analysis (Gane and Sarson [44]). However, several researchers have investigated the applicability of IDef0 (a method developed from the earlier SADT) as a method of process modelling for quality improvement activities (Tannock [131], Maull [86]). Their findings suggest that IDef0 can be employed by a broad spectrum of company employees after a little training (although Crossfield et al [21] have proposed a slightly modified form of IDef0, which he claims to be more easily understandable for the novice). Whilst computer support is available for many modelling tools, for the most part such software is expensive and often not suited to occasional use by novices; the usage pattern most likely in process analysis for quality improvement. This niche (ie. an easy to use, cheap computerised modelling tool) has been investigated by Tannock and Wort [133].

During the project from which this thesis is derived, two of the team members used IDef0, one used the Viable Systems Model (Harwood [51]), and the author used the standard Systems Analysis Data Flow Diagrams. The models produced by these three methods were the main interface between the team members, and it is interesting to note that, on several occasions, differences in the representations of a process deriving

from variations in the modelling technique clarified differences in the perception of the process between team members. Although it is perhaps significant that it was most frequently the author (an experienced Analyst/Programmer) who was called upon to work with the models drawn up by the other teams members, and thus with less familiar data modelling techniques.

A final point which must be noted with regard to measurement is the need to ensure the correctness and suitability of the measuring devices employed. Thus it is vital that the capabilities and range of applicability required to measure some specific characteristic be clearly understood so that measurements are not rendered meaningless by the use of inappropriate equipment. Furthermore, it is necessary that a system exist whereby measuring devices are regularly checked and calibrated to ensure their continued accuracy.

2.3 Statistical Process Control (SPC)

In order to assure quality it is necessary to demonstrate that production processes are able to perform their appointed task reliably and with a high degree of consistency. Statistical Process Control (SPC) provides the requisite evidence of process capability, and can further be used as a tool in a programme of continuous improvement.

In 1931 Shewhart [116] explained the concept of statistical control as a means of identifying whether a process was being affected only by acceptable random variations

(common causes), or was subject to specific additional perturbations due to some special "assignable cause". Once the effect of an assignable cause (for example, machine malfunction) was detected steps could be taken to identify and eliminate this cause of unacceptable variability so that the process could be brought under statistical control. Once a process had been established to be in control, its performance could be analysed to determine its capability to perform its task. An incapable process may be under statistical control but is not good enough to achieve the standard of product quality required of it. Since such a process was already in control, improvement by the elimination of assignable causes is not possible (by definition a process under control will not normally exhibit such problems), so, to achieve the improvement necessary to attain the required capability, the process itself must be modified in some way (for example, tooling or jig changes, different operational procedures, changes in raw materials).

This new technique was a much needed breakthrough, and forms the basis of modern quality control. For the first time, it was possible to systematically improve the performance of production processes on the basis of statistical analysis of information gleaned from inspection. Once a process had been brought under statistical control, and its capability had been established, inspection levels could be reduced because reduced variability meant fewer non-conforming products. Therefore overhead costs were reduced, both in respect of inspection and lower scrap levels (Kearney [67], Dwyer [33]).

During the Second World War, Shewhart's technique was adopted in the manufacture of munitions. In the UK, the Ministry of Supply recommended the use of Shewhart's ideas to help the war effort. The young Deming worked with Shewhart and, in his later work with the Japanese, placed much emphasis upon the use of the methods of statistical process control proposed by Shewhart. As a result the Shewhart Control Chart is now very widely used. A comprehensive guide to Statistical Process Control (including advice about the pitfalls which may be encountered) is given by Owen [99]. The importance of thorough, correctly pitched training to the success of SPC within a quality improvement programme cannot be over-emphasised (Owen [100], Murdoch [92]), for there is evidence of misunderstanding, even within the literature on the subject. For example, Barrett [5] incorrectly states that one of the criteria used to determine that a process has gone out of control is that seven consecutive readings fall outside the control limits. This is a confused combination of two separate indicators of an out of control process; firstly, a single point falling outside the control limit, and secondly, the occurrence of a highly improbable (statistically) sequence of seven consecutive points for example, on the same side of the mean (but still within the control limits), or in a run which is either consistently increasing or consistently decreasing (Owen [99], Ford Motor Company [43]). In their description of the evolution of SPC within their plant from 1982 to 1989, Cantello et al [14] identify a number of factors which limited or slowed down effective implementation of SPC.

Typically SPC is applied to manufacturing process, however, many quality failures arise from non-production processes (Crosby [20] cites that at least 25% of all

non-manufacturing tasks require some form of rework). SPC can be used to monitor and bring under control such things as incorrect invoices, duplication of orders, missed appointments, delays in answering the telephone, or time taken to respond to customer complaints. For example, Nowak [95] has examined the applicability of SPC to the control of errors in a stock control system.

2.3.1 SPC Automation - Benefits and Dangers

SPC is an obvious candidate for computerisation because of the well defined, moderately simple nature of its statistical rules. It is not surprising, therefore, that a very large selection of products have been developed to aid in the collection and analysis of data for SPC. These products range from the fairly simple (something along the lines of a fancy pocket calculator with a till roll style printer to produce permanent records of the control charts) up to quite complex microcomputer based systems. Many production machines and monitors have SPC functions built in because automatic SPC has become an important sales feature.

Ford Motor Company have incorporated SPC (in a slightly simplified form) in their quality standard Q101 (Ford Motor Company [42]). Ford initially trained their staff in manual SPC, and are thoroughly convinced of the importance of this type of operator involvement for the success of their quality improvement programme. However, where a number of product or process features have to be simultaneously monitored, manual SPC becomes problematic. This hinges on two factors; firstly, the time taken for an

operator to take requisite measurements and plot them onto the Control Chart, and secondly, that the number of control charts to be maintained and watched becomes physically unmanageable. From this situation arises the need for automation in data collection, control chart maintenance and monitoring. In order to assure themselves of the capability of any SPC package which was to be used within their organisation, Ford commissioned an independent firm of consultants to test and certificate such products against the requirements of Q101. The results of this testing are reported by Jones [61], they demonstrate clearly that many companies are adding on SPC modules to their products simply because their competitors have done so, although, in many instances, they do not have sufficient expertise to produce a reliable, accurate product. The packages examined were frequently found to have mistakes in the calculation formulae being used, limitations in the rules for detection of out of control situations, poor graphics and reports, and a host of other failings. To date, few SPC packages have successfully obtained the certification necessary to satisfy Ford's requirements.

Stanton [122] warns of another potential problem with SPC automation which stems from the external imposition of techniques such as SPC. The insistence of Ford that suppliers conform to Q101 has not always led to the improvement anticipated in supplier's quality systems. Hakes [50] has described how, during a visit to a Ford supplier, he encountered an inspector carrying a hand-held SPC analyser. He discovered that the SPC analysers had been introduced in response to a Ford requirement for suppliers to send control charts with their products. Unfortunately, neither the reasons why Ford felt SPC to be important, nor the benefits to be gained from the use of SPC,

had been successfully communicated from Ford to the supplier. Therefore, the supplier was collecting data and sending it on up the supply chain to Ford without ever recognising that the data identified problem areas needing corrective action. Furthermore, it is interesting to note also that, at the time of Hakes' visit, there was no evidence that Ford had in any way reacted to the clear indications of lack of control shown in the documentation which they were being sent. The lesson to be learned from this example is that it is vital that suppliers understand that SPC is not just an irritating overhead imposed upon them by their customer, but that it can help them improve their processes and product, and often their profit margin.

2.3.2 SPC Information Requirements

SPC charts, produced by the measurement of variable or attribute type characteristics (eg. temperature of a furnace, weight of a moulding, presence of blemishes in paintwork, missing pins in a connector) of the product by analysing small samples taken from the process at regular intervals, service the quality improvement effort in several ways.

Initially, SPC is used to demonstrate that the process being monitored is under statistical control and is capable of meeting the product specification consistently. This is evidenced by an even distribution of measurements around the process mean in which there is only a limited degree of variation from the mean, such that no data falls beyond 3 standard deviations from the mean; ie. that the collected data conformed to the

normal distribution. This analysis of process capability is carried out under normal operating conditions, but with no operator intervention for adjustment of the process being permitted during the study. No data beyond those characteristics being monitored in the study is necessary for the determination of process capability. However, the results arising from the capability study may require additional information input where either the process was found to be in statistical control but not capable, or the process was out of control. In the former case, it is necessary to investigate means of improving the process as a whole, by finding the means of moving the process mean towards the required specification. Such investigation may take the form of a programme of designed experiments to study the effects of proposed changes to the process (eg. different raw materials), or the attention of a Quality Circle to design new jigs or tooling. In the later case, there is a need to eliminate factors which are causing undesirable variation in the process. The approach used may be similar to that taken in the former case, although the effort must be focused on the identification and removal of causes of variation, rather than achieving a shift in the process mean. The common need of both situations is that analysis of data beyond that being monitored to create the SPC charts is necessary to identify ways of improving the process.

In a case study, Griffiths [48] describes the monitoring of energy consumption in a process capability study in the Iron Founding industry. This study demonstrated the need for process improvement, resulting in analysis of mould performance, working practices of operators, production variations and interaction of other influential factors. Mellichamp et al [89] discuss the use of a computer aided system (known as CAMQ)

for performing capability studies with a view to machine qualification. This package provides guidance in the method to be used for the study, recommendations on qualification of measuring and gauging equipment, suggestions as to areas where improvements might be sought, and documentation of the whole qualification procedure for company records.

Following the capability study, SPC is used to monitor and control the performance of the process during production by periodic measurement of significant process or product characteristics. Action is taken by the operator only when the SPC chart shows the presence of some special cause of variation via an extreme result from a sample, or when there is evidence of a non-random trend in a sequence of samples. When a special cause is indicated, the operator must investigate external influences on the process to determine what has caused this unusual variation. It should be noted that in some cases special causes lead to an improvement in the process performance, so that efforts must be made to modify the process to include the influential factor as a regular component of the process.

SPC charts are often used as a means of demonstrating to customers that proper quality control procedures have been applied to ensure that products conform to specification, and that corrective action has been taken as required to improve the process.

To support an SPC programme, it is recommended that the integrated quality database should provide access to information pertaining to all aspects of the manufacturing

operation, either as the repository for such data, or via interfaces to other systems. Furthermore, that the database should be used as a storage device for historical SPC results, which might then be used within the supplier-customer relationship as evidence of process control, and also as a defence in case of prosecution under the Product Liability Law. However, it is believed that detailed support of SPC should be left to specially developed packages (many of which are already available), but that the usefulness of this technique could be extended by the provision of additional information (other than that being directly monitored) via the quality database, so that the effects of external factors on process performance can be more thoroughly investigated. A summary of the SPC-related Data Flows is given in Figure 2.1.

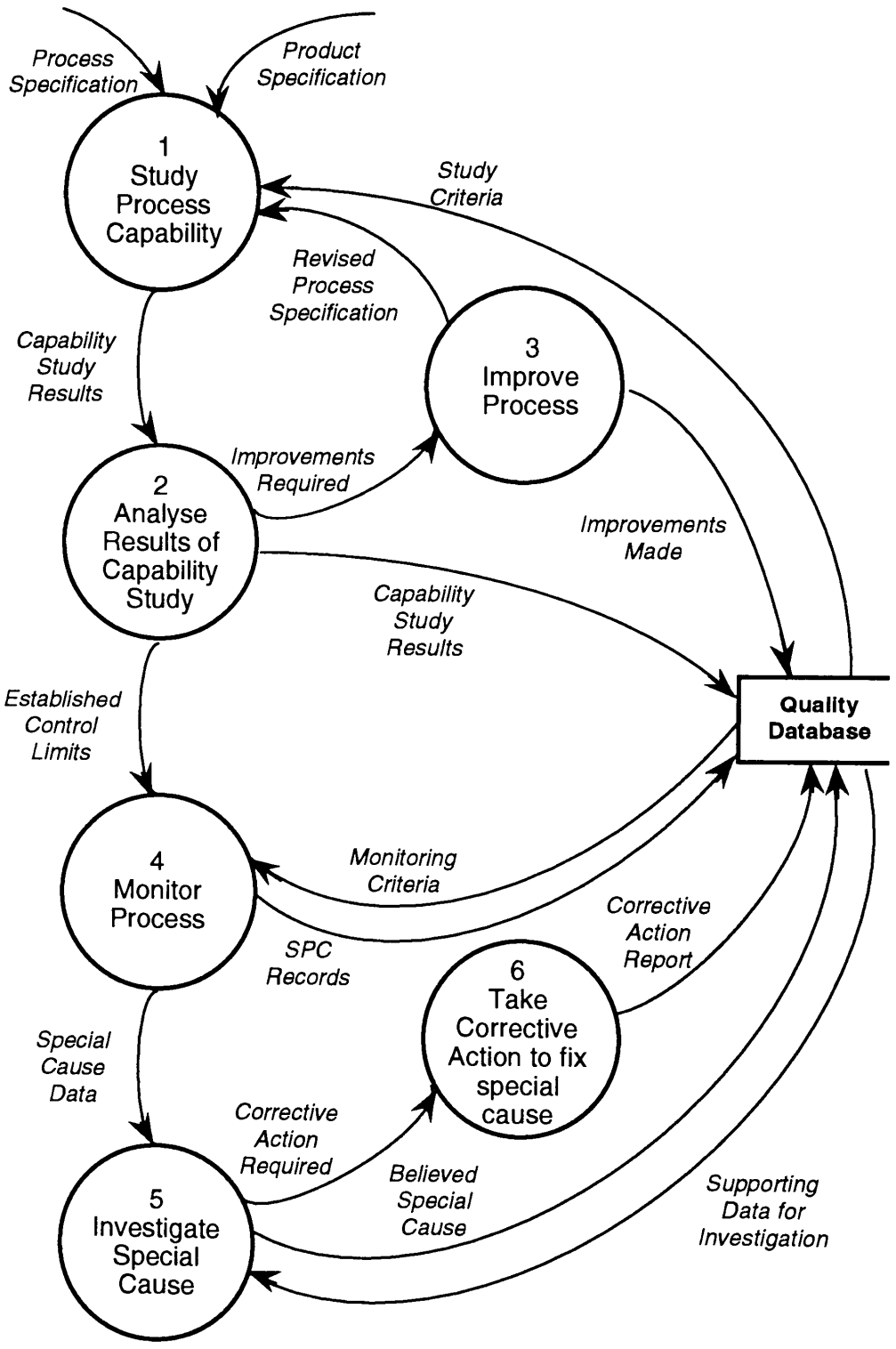


Figure 2.1: Data Flows in SPC

2.4 Quality Circles

Quality Circles were first promoted when Dr Kaoru Ishikawa and JUSE developed a set of Quality Control Circle training materials for use in Japan in the early 1960s (Ishikawa [58]). After a slow start, Circle programmes became increasingly popular, so that in 1970 the first known American Circle was started (Patchin [102]).

Quality Circles depend very heavily upon the willingness of shop floor workers to become actively involved in problem identification and analysis. Schonberger [115] attributes the initial generation of such interest to Just-in-Time production management which he believes makes more evident to workers how dependent they are upon one another.

Typically, Quality Circles are teams of between 4 and 15 shop floor workers normally lead by a supervisor. All participation is voluntary, and the group are free to choose their own problem to investigate. Above the Circles is a Facilitator whose function is to provide support services to the Circles, for example, the selection and training of Circle leaders (Aymie et al [2], Crowell and Settle [22]), the provision of training in analysis methods, supply of information beyond the reach of the Circle and other support necessary to assist their investigations (Culbertson [23]). It is also the Facilitator's duty to act as an interface between the Circle and middle management (Obringer [97]), and to keep workers not involved in the Circle informed of the progress of Circle investigations. The Facilitator is in turn responsible to a management committee who take executive responsibility for the Circle programme as a whole

across the organisation (Ruchti [112]).

Circles meet on a regular basis (normally during working hours). Dale [27] reports that frequency of meetings for established Circles varies from one hour weekly to one hour monthly, although new Circles usually meet on a weekly basis initially. The group identify a problem which they wish to investigate. This is often a quality problem, but may equally well be related to cost savings, increasing productivity, improving the work atmosphere, safety or any other issue which concerns the group.

Having identified a problem, the Circle use techniques such as Pareto analysis, Brainstorming (VanGundy [140]), Cause and Effect analysis, and a variety of other simple statistical analysis methods to gain a fuller understanding of the situation (Swanson and Scherer [128], Caulcutt [15]). For the most part, the data needs of Quality Circles are simple and easily obtained by the Circle members themselves, however, on occasions the Facilitator may be requested to supply additional information or analyses, in which case there is a need for a central data store through which the Facilitator can obtain the required information. The Circle members then investigate possible solution paths, and finally make a formal presentation of their findings to senior management. It is then up to management to take any necessary action to implement the Circle's recommendation.

Although Quality Circles have gained the reputation of being a major contributor to the success of Japanese quality improvement programmes, in Western industry (in

particular in the USA and UK) they have failed to match the achievements of Japanese Circles. Lack of management support in following up Circle reports is cited by Hill [54] as one of the two main reasons for the complete termination of Quality Circle programmes in British companies (the other significant reason being factory closure or high redundancy levels due to economic difficulties). These are also high on the list of reasons for failure of individual Circles. These findings are backed up by Luzon [82], who emphasises the need for culture changes to support a Quality Circle programme. In his 1987 paper, Guthrie [49] examines the failure of the Quality Circle programme initiated by the Ford Motor Company in the early 1980s. This failure was blamed by the company on lack of co-operation from the Trades Unions. However, Guthrie's conclusion was that the fault actually lay in a fundamental misunderstanding by top management of the true nature of Quality Circles. In implementing the programme neither Trades Unions nor middle and lower management were consulted, they were simply told that Quality Circles were to be introduced. As a consequence the programme was surrounded by resentment, distrust and a lack of understanding of the Circle concept. Gibson [45] highlights the need for continual assessment and measurement of Circle progress by reporting the shut down of a lively, active Circle programme because a newly appointed company president demanded evidence of the cost effectiveness of the programme. Since no information on the financial benefits accruing from the improvements achieved through the Circle programme had been collected, justification of the payback from the programme was impossible, and so the new president closed it down.

Tanaka [130], the leader of a Japanese Quality Circle gives lie to the commonly held view that in Japanese industry Circle programmes run without problems because of an inherent culture difference. In his paper, he relates the history of his Circle through several periods of difficulty and uncertainty caused by instability in the membership of the Circle, recession, poor relations with non-circle workers and the internal relationship dynamics of the Circle itself. This paper makes interesting and enlightening reading, and clearly demonstrates that commitment from workers and management alike is vital to the success and survival of any Quality Circle programme, whether in Japan, USA, UK or any other country.

2.4.1 Information Needs of Quality Circles

In their day to day operation, Circle members decide what data they feel should be studied in order to gain an understanding of the influential factors in the problem which they are considering. For the most part, the data collection methods are designed and implemented by the Circle members themselves. The factors being studied have usually not been monitored before so there tends not to be any legacy of previous results available. In some cases, however, the Circle will feel the need to consider their problem in the light of information to which they do not have access. In this situation it is the responsibility of the Facilitator to obtain the required information for them. It is in the fulfilment of this duty that the Facilitator might usefully be supported by a database of quality related information, supplemented by access to information not falling within the traditional remit of quality via a central data server. However, on the

basis of reports such as Campoli [13] and Communication Line Circle [18], it appears that the inherent simplicity and "do-it-yourself" emphasis of the Quality Circle philosophy would tend to militate against reliance upon any central data source during Circle investigation, although the project reported by Kemp and Jontz [68] does suggest that the team might have found use for a spreadsheet or simple statistical package during the course of their investigation. Figure 2.2 shows the type of data flows which might exist in order to support Quality Circle activity.

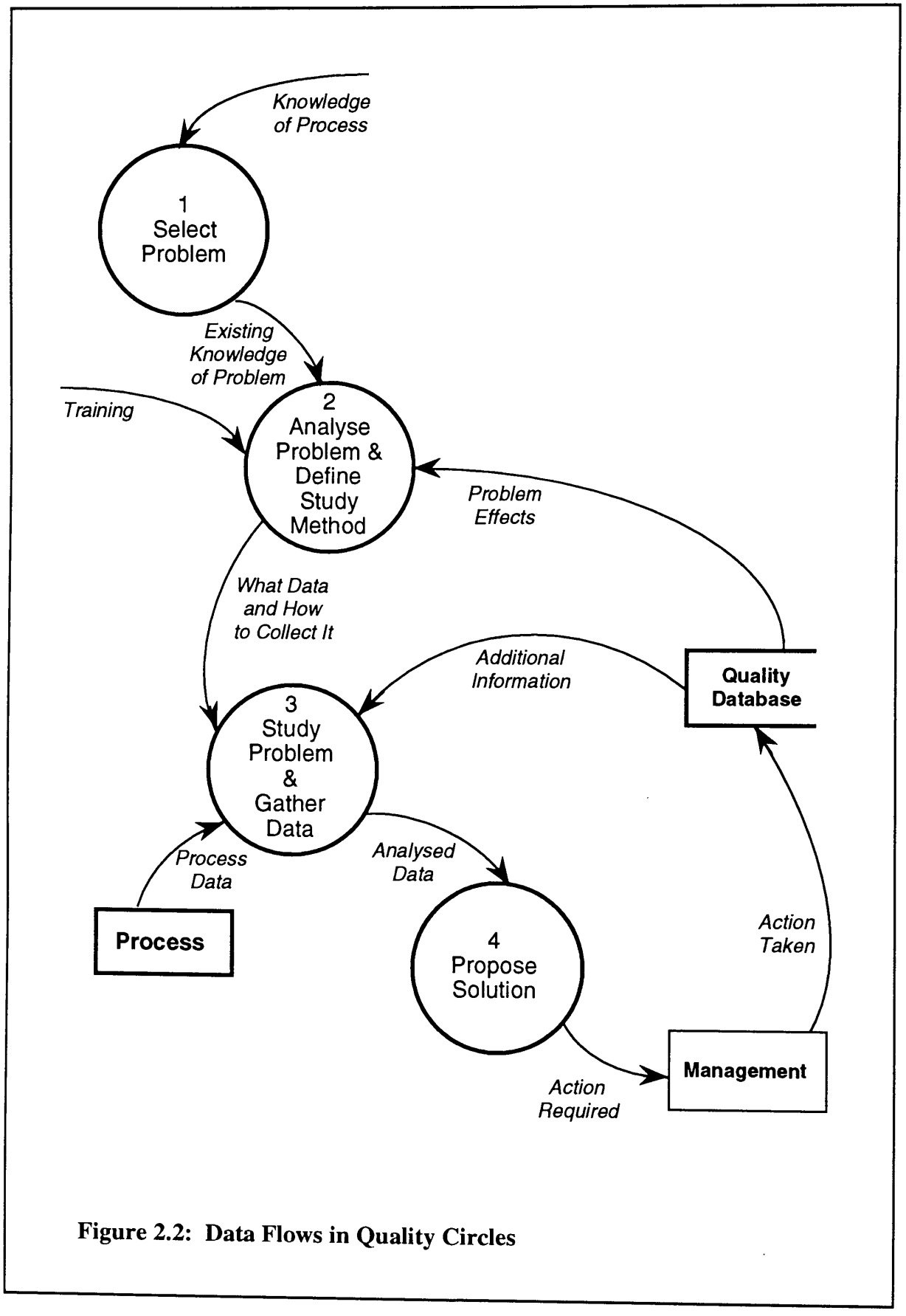


Figure 2.2: Data Flows in Quality Circles

2.5 Failure Mode and Effect Analysis

Failure Mode and Effect Analysis (FMEA) (sometimes referred to as Failure Mode, Effect and Criticality Analysis (FMECA)) is used in the design and pre-production planning phases of the manufacturing process. Its aim is to examine all parts of the product and manufacturing process with a view to foreseeing potential failures of the product in service. Having established how the product might fail, it is necessary to determine the severity of the likely effects of such failure upon the customer, and to identify possible causes within the design or manufacturing process. FMEA is described in more detail in Ford Motor Company [41], Feigenbaum [37] and Sinha and Willborn [118].

The inputs to this process come from several sources. Firstly, historical records of known failures in earlier, similar parts may be examined. These records should also identify the causes of failure and any corrective action which was taken. This historical data is likely to be composed from warranty claims, customer complaints, internal quality control and inspection records, and reports concerning servicing in the field. The second source of possible failure modes comes from the analysis team (usually a multi-disciplinary group), who draw upon their experience with the help of techniques such as brainstorming to maximize fault identification.

Once a set of potential failure modes have been identified, the team considers the severity of each fault, as it would affect the customer. For example, a car which has a leaky sunroof is irritating to the owner but not potentially hazardous, while brake

failure may well be very dangerous, both to the driver and others.

In order to improve the design or process, it is necessary to determine possible causes for each failure mode, and to ascertain the probability of failure because of each possible cause. Then the planned quality control mechanisms must be examined to establish the likelihood of detection of the defect prior to release to the customer.

Finally, the risks associated with each type of failure are estimated, and corrective actions are planned (sometimes with the aid of a programme of designed experiments) and implemented. After this the FMEA should be reviewed to check that the corrective actions taken were effective.

The computerisation of FMEA has been addressed by several systems. Coker et al [16] examine a program based on Lotus 1-2-3, however, it appears that, while able to provide access to SPC records and previous FMEA studies, this system would not be able to supply all the historical data which may be needed (for example, warranty and customer complaint records). Thus the linking of such a system into a company wide integrated database, able to provide access to this additional information, would be beneficial. Figure 2.3 shows the data flows which support FMEA.

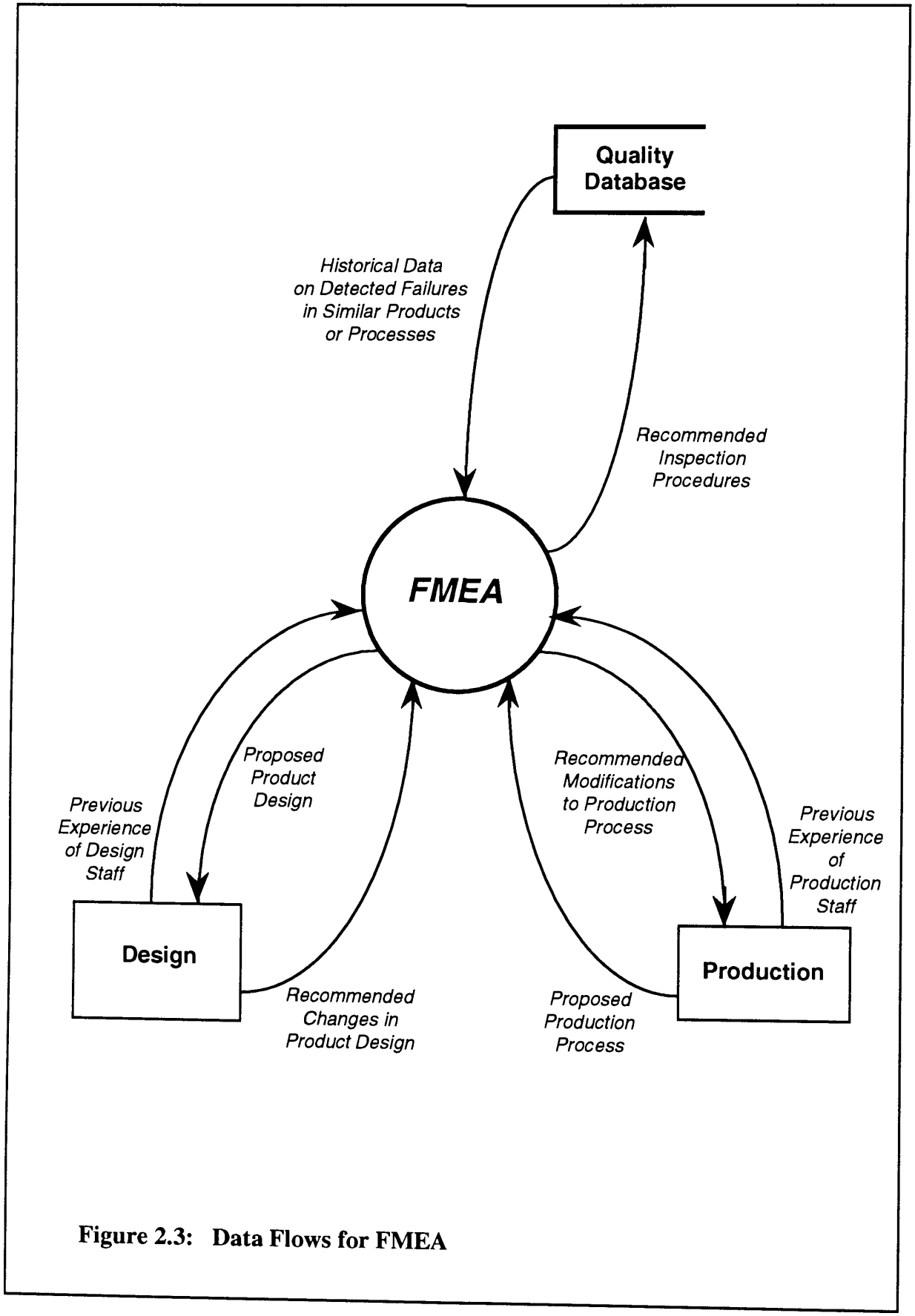


Figure 2.3: Data Flows for FMEA

2.6 Experimental Design

The concept of a "Designed Experiment" has arisen from scientific research where there was a need to undertake controlled, systematic comparison of the results of experiments in order to determine the relationships between, and influences of, numerous factors which could be varied by the experimenter. So as to ensure, as far as possible that the experimental results were not influenced by such things as the experimenter's personal bias, effects due to the sequencing of experiments with different factor levels, and effects of external factors not under the control of the experimenter (e.g. laboratory conditions such as temperature or humidity), various statistical methods have been developed.

These methods may be used to plan the number of experiments necessary to examine adequately the various combinations of the factors under consideration, to decide how many repetitions of the experiment should be made for each combination, how to group the experiments so that equality of external conditions may be achieved, and so on. A full discussion of the statistical techniques available for experimental design is beyond the scope of this thesis, however details may be found in a number of texts, for example, Cox [19], Hunter et al [55] and Mead [88].

The use of formally designed experiments has a twofold impact on quality; firstly, they may be used as a means of optimising both product and process prior to the commencement of production, and secondly, as a means of investigating problems which have become manifest either in the product or process during production, or

through product failure in the field. Probably the most well known being the simplified method proposed by Dr Genichi Taguchi.

2.6.1 Taguchi Methods

Taguchi views quality from a somewhat unusual angle in that he defines product quality in terms of the losses incurred by society as a result of the failure of the product. His point of attack with respect to quality improvement reflects this view. He believes that quality and reliability are issues which must be addressed at the design stage; to solve a problem once the process is under way and products are being made is far more costly than designing out problems in advance, during the design phase. He therefore advocates the routine optimization of product and process prior to manufacture (Sullivan [126]), although his experimental design techniques can also be used as a trouble shooting aid for solving production problems which come to light during manufacture. The goal of this optimization is to make process and product as robust as possible; that is, as insensitive as possible to changes which may occur in any noise factors. A noise factor being any variable (such as ageing and maintenance of equipment, or environmental conditions) which is uncontrollable in production. A full explanation of Taguchi methods is beyond the remit of this thesis, but is given in Taguchi [129], Barker [4], Roy [111], Kackar [64], Kumar [74], and Bendell and Disney [8], illustrative examples are given by Goh and Roy [46], and Simmonds [117].

Taguchi methods have been adopted by a number of companies (eg. Digital Equipment

Corporation (Nicols [93]), Sheller Globe, Flex Products, Dana Corporation, Ford Motor Company, General Motors (Sullivan [126]) who claim to have achieved worthwhile improvements as a result. However, the statistical rigor of these techniques has been attacked by members of the statistical establishment (Kackar [64]). Another criticism which has been levelled is that the statistical simplifications which allow Taguchi methods to be used by those lacking detailed statistical training, in themselves present hidden dangers which would be obvious to a statistician, while a layman would not know to look for them.

2.6.2 Computer Support for Experimental Design

Two types of computer support may be of use in the design of an experiment, whether it be for planning or problem solving. The more obvious is clearly the use of a statistical package for the analysis of the experimental results. Perhaps less evident is the value of historical data related to the proposed experiment. The design of a series of experiments will be influenced by knowledge of the situation in which the experiment will be carried out. For example, the blocking of the experiment may be dependent on shift patterns or other cyclic changes (one company found that the accuracy of some of their machines varied with the state of the tide because of the geological structure of the site on which their factory was built). Also of interest might be known variations in the performance of different pieces of equipment or raw materials expected to be used in the study. Access to, and analysis of, such information can best be provided for via a database which has the capability of integrating data from various sources across

the organisation (e.g. manufacturing data, including production plans and sources of raw materials). Figure 2.4 shows the data flows involved in the Experimental Design and analysis process.

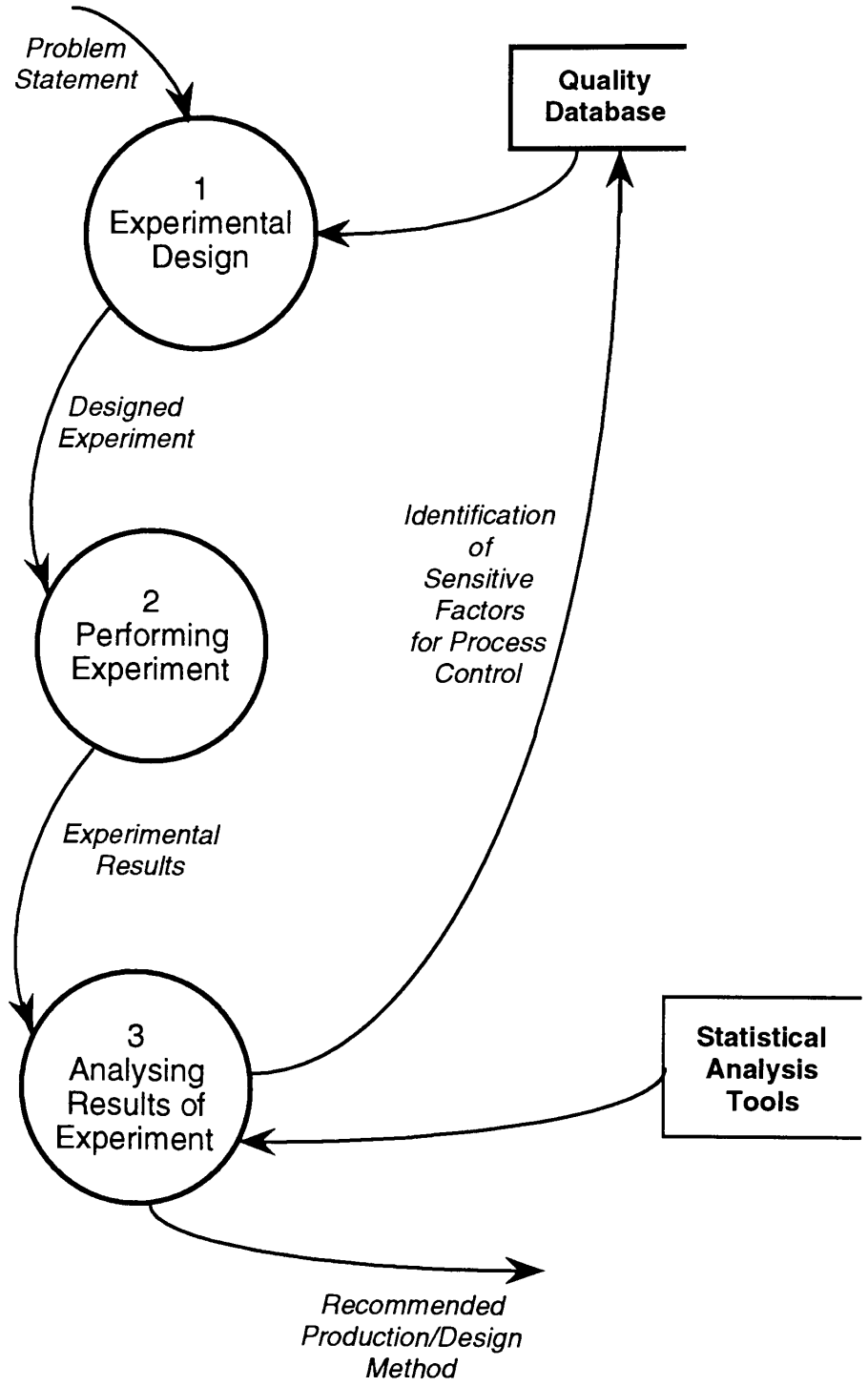


Figure 2.4: Data Flows for Experimental Design

2.7 Quality Costing

While Quality Costing cannot really be considered to be a quality assurance technique in the truest sense, it does have a very important role in the life and monitoring of quality assurance programmes (Stolber [124], Dane [28]).

The cost of quality is defined as including the costs of assuring quality (ie. prevention of defects and detection of non-conformance), combined with the costs associated with quality failure (eg. warranty and service costs, scrap and rework, loss of customers, loss of reputation). It has been demonstrated that relatively small increases in prevention costs can lead to large decreases in those costs associated with quality failure (Plunkett and Dale [107], Crosby [20]). Jordan [62] considers the practical side of Quality Costing.

In order to obtain an accurate measure of quality costs, it is necessary to combine cost data culled from all parts of the operation, for example, wages (analysed by function), training expenses, rejection rates at each stage of the process, cost of rework, running costs of machinery, etc. This process could be made much easier by the availability of a single means of accessing this data, thus linking financial, personnel, manufacturing, design and other information systems. Such a means could be provided by the integrated quality database proposed in this thesis.

Chapter 3

Standards, Legislation and Quality Awards

3.1 The Need for Standards

Standards exist in order to provide conformity. It is necessary that both supplier and customer measure a product consistently, ensuring the same point of measurement, judged against the same criteria; this consistency may be achieved by the comparison and calibration of internal measuring devices against a standard measurement held and guaranteed by a third party, combined with explicit declaration of the point of measurement and criteria for judgement. A description of the origins of standards is given by Khan and Hashim [70], while Spickernell [121] discusses the relationship between standards and quality.

Conformance to standards, such as BS 5781 (Measurement and Calibration systems), which define the criteria for judging the accuracy of equipment and specify rules for calibration, is of prime importance in the development of a competent quality assurance system, because without accurate and reliable measurement, any attempt to analyse process capability or product quality is meaningless. It is therefore necessary to monitor and control the maintenance, calibration, and use of all measurement devices to ensure that they are being correctly operated and able to produce accurate, repeatable readings at all times. The use of SPC as a means of establishing the adequacy and reliability of test and measurement equipment is described by Bishop et al [9].

Such standards provide guidance for the correct provision, maintenance and application of many elements of the production cycle. As free-standing articles there is much need for their use, however, to gain in full from their application it is necessary to integrate individual standards (for example, in the areas of measurement, calibration, or materials testing) into a uniform whole: a system, so that they might complement one another. Thus, despite the importance of product and process measurement as a means of verifying correctness (dimensional or otherwise) of a product, the assurance of quality must be based on a sound system to ensure the correctness of all aspects of the production (or service) cycle; design, reliability testing, marketing, setting up the production process, production, despatch and financial services. The system must be robust, self checking and self correcting. It is not sufficient for the system to keep working; it must also keep improving by constant self monitoring to detect areas of weakness where improvement action may be applied, and then studied to ensure that those actions had the desired effect.

3.2 Quality System Standards

BS 5750 was developed in response to this need for the formalisation of a control system for quality. It is designed in such a way as to allow its application in any industrial sector; having parts which apply to:

1) Part 1: The entire manufacturing cycle, from design and product development through to installation and servicing.
2) Part 2: Production and installation.
3) Part 3: Final inspection and test.

Part 0 provides and overview of the concepts and applications of the standard. Part 4 is a guide to the use of parts 1, 2 and 3. These parts comprise the original elements of BS 5750. In 1991, however, two additional parts were added. Part 8: Guide to quality management and quality system elements for service, and Part 13: Guide to the application of BS 5750: Part 1 to the development, supply and maintenance of software.

BS 5750 was subsequently adopted as the basis for the ISO 9000 series (which comprises ISO 9000, 9001, 9002, 9003 and 9004) and also for the equivalent European standards, EN 29000, 29001, 29002, 29003 and 29004.

These standards, while a valuable contribution to a general trend of quality improvement, are not perfect (Dagnino [26], Jennings [60], Whittington [145]). They impose a high overhead because of the large amounts of documentation which they require and tend as a result to deter the formal recording of changes in procedures. Hersan [52] identifies several point at variance with accepted Quality Assurance theory; for example, the relative weightings of inspection and testing activities in comparison with assurance, failure prevention and system management tasks. He also identifies some missing requirements; these being standardisation of units, marketing, corporate planning, cost control. Furthermore, he highlights the need to create and nurture staff motivation towards quality improvement. For small companies wishing to put BS 5750 into practice Lintern [79] and Whitehead and Alley [144] consider the problems which might arise and how to deal with them.

BS 5750 is supported by an array of more specific quality related standard focusing on particular quality assurance activities. BS 5760: Reliability of systems, equipment and components; this gives guidance on management of reliability programmes, assessment of reliability, good practice, reliability related specification clauses, FMEA, FMECA and fault tree analysis, and finally, reliability growth. BS 6548: maintainability of equipment; including maintainability studies during the design phase. BS 6143: Guide to the economics of quality; including the process cost model and the prevention, appraisal and failure model. BS 7000: Guide to Managing product design; which discusses corporate level management as well as project level control. BS 7229: Quality systems auditing; this is of use both for internal assessment of the quality system and for judgement of supplier competence. BS 7373:The preparation of Specifications is important because the specification is the principal means of communication between the customer and the manufacturer; if the customer's needs are not clearly and unambiguously stated it is unlikely that the supplier will correctly interpret them. Thus the specification has a primary role in assuring customer satisfaction.

In 1992, a new standard was published to address an increasing demand for guidance in the application of Total Quality Management. BS 7850 is in two parts; Part 1: "Guide to Management Principles" and Part 2: "Guide to Quality Improvement Methods". Because of its very recent publication, it was not possible to take its requirements into account during this investigation. However, a review of the system proposed herein indicates no conflict.

Quality System Standards (such as BS 5750) are considered dangerous by many authorities on quality because of the implication that conformance to a Standard denotes that quality has been achieved and therefore nothing more needs to be done. This argument may also be applied to other standards, for example, applying to safety; while it is clearly necessary for there to be defined minimum levels of required criteria below which a product or service is considered unacceptable, these standards should be considered in the same light as, for example, examination results; the pass mark indicates that level where a student is considered to have achieved the minimum acceptable level of competence. However, it is usual for results to be given in more detail than a simple Pass/Fail, so that it is possible to distinguish between the barely capable student and the extremely good, and by degrees within these extremes. Despite this potential trap, Quality Standards are an important part of the quality improvement process; firstly, because the need to conform to some standard in order to satisfy customer requirements often provides the initial impetus for a commitment to the development of a true quality assurance system within an organisation; secondly, because standards provide direction and guidance in the design and functionality of quality assurance systems; and thirdly, because standards provide a measure against which quality assurance systems can be judged to determine whether they achieve a minimum level of competence.

However, organisations wishing to compete in world markets must not rely on simple conformance to quality standards in order to win contracts because they will be in competition with companies which take the stance that, in all their activities, only the

best is good enough. Such companies are always striving to improve the quality of their service to customer, supplier and worker, and will therefore be competitive not only in conformance to standards, but also in product or service quality, price and lead time.

Because certain large companies impose their own standards on their suppliers in preference to national or international standards, there may be a need for a given supplier to conform to several standards simultaneously. Thus there may be conflicts which must be arbitrated between the requirements of the various standards which must be applied. This may also lead to duplication of records for use under different standards.

A detailed analysis for the requirements of the various quality standards applicable to different sectors of engineering industry (in particular automotive, aerospace and defence, and general engineering) is beyond the scope of this thesis.

3.3 CALS

In addition to the demands of existing Standards, it is necessary, in considering the design of an information system to support Quality Assurance activities, that the projected influence of the US Department of Defense's Computer-aided Acquisition and Logistics Support (CALS) programme be taken cognisance of (Williams [147]). This programme has already produced a number of US standards (Strain [125]) which have bearing upon the specification, design and implementation of information systems, data

storage, retrieval, presentation and transmission (MIL-HDBK-59 and 59A, MIL-STD-1388-1A, 2A and 2B, MIL-STD-1840A, MIL-D-28000, MIL-M-28001A, MIL-R-28002 and MIL-D-28003). Since CALS is still under development, any new computer systems developed must be designed for future adjustment to meet the requirements of CALS, which is likely to become a mandatory requirement for US Defense suppliers (Virgallito [142]). Since many UK and European companies supply or sub-contract on US Department of Defense contracts, it will soon be necessary for them to adopt CALS. Clearly, the predicted benefits which have driven the US to develop CALS would also be of worth to European industry and governments, therefore members of the European Community are working with the Americans on the further development of CALS (Smith [119]).

3.4 Product Liability

The other issue which must be addressed is that of Product Liability. Recent revisions in Product Liability law reverse the earlier position wherein an injured customer had to prove negligence on the part of the manufacturer in order to win damages (Sale of Goods Act). The new law (an unusual combination of Civil and Criminal law) however, places the burden of proof upon the manufacturer to demonstrate that all proper quality procedures were followed, that safety issues were properly addressed, that any applicable standards were adhered to, and that the product was in satisfactory working order on leaving the factory. In order to provide this evidence, it is necessary to maintain records concerning all these things.

Clearly, the best defence against prosecution under the Consumer Protection Act (1987) is to ensure that all products are produced under strictly controlled conditions so that they do not fail in use and cause injury or damage to property. To a large degree, this can be achieved by the development and use of comprehensive quality assurance procedures covering all elements of the production process, including design, manufacture, packaging, writing of instruction for use, including cautions against misuse, and control of advertising and marketing to ensure that misleading claims are not made for a product.

The Act is divided into three parts; Civil Liability, Criminal Liability, and Misleading Price Indications. In addition, in schedule 3 it changes the rules on safety of work equipment set out in the Health and Safety at Work Act (1974), replacing the phrase "in proper use" with "at all times".

Part 1 extends the rights of a consumer over and above existing common law and statutory rights, whilst Part 2 deals only with the safety of consumer goods and imposes criminal liability on suppliers whose goods fail to meet safety requirements.

In order to bring an action under Part 1 of the Consumer Protection Act a plaintiff must be able to prove three things; that he has suffered damage, that there was a defect in the product, and that it was the defect which caused the damage. However, even when these three things can be proved, six defences are admissible.

Firstly, that the defect is attributable to compliance with mandatory enactments or obligations (though this does not apply to advisory standards where compliance is not an admissible defence).

Secondly, that the product was not supplied by the defendant at any time (this covers stolen goods and counterfeit items).

Thirdly, that the defendant did not supply the product in the course of business (the church bazaar jam stall clause).

Fourthly, that the defect did not exist in the product "at the relevant time" (typically, but not always, at the time of sale/delivery).

Fifthly, that the state of scientific and technical knowledge at the relevant time was not such as to enable the presence of the defect to be discovered.

Sixthly, that the defect in question was in the finished product as a result of a component manufacturer complying with the instructions of the producer of the finished product (the component manufacture's defence).

It may be seen that several of these defences hinge on the ability to provide evidence of compliance to mandatory requirements (1), proof that quality assurance activities had been properly carried out (4 & 6) (although this may in some cases lead to reduction

of damages, rather than acquittal).

Whilst the Consumer Protection Act applies to products which are not more than 10 years old, it seems likely that it will be necessary to keep the relevant records for a total of 17 years because the legal process may take as much as 7 years in the event of a conviction against which an appeal is lodged. Given the rarity of organisations who routinely keep records even for 10 years, there are likely to be many companies which will need to undertake a major review of their records and institute new procedures to address the question of data provision in case of the need to provide a defence in the face of prosecution under the Consumer Protection Act. The physical problems associated with the maintenance of such a wide variety of records on paper (or even microfilm) for such a long period are considerable, but they pale into relative insignificance against the problems of accessing the relevant information in the event of a prosecution. It is therefore necessary to establish a database to allow both efficient data storage and convenient information retrieval. There is, however, some question about the status of computer data as evidence, although it is clear that this issue must be addressed in the near future, particularly in view of the likely advent of integrated computerised data exchange as a result of CALS.

3.5 Quality Awards

While not applying the same level of compulsion as standards and legislation, quality awards are a useful impetus in stimulating quality improvement because the gaining of an award can be a powerful publicity tool and a great advantage in competition. However, benefits also come from carrying out the recommended internal self assessment prior to entering for an award. Firstly, because the prescribed application documentation provides a structure for a thorough examination of the whole business and poses questions which focus attention on crucial areas. Hence, assessing the organisation using the award framework can provide a comprehensive analysis of the quality health of the organisation for management to act upon since it highlights strengths and identifies those areas which need to be addresses. This is true even where an application is not subsequently submitted for the award. Secondly, every application submitted for the award will be thoroughly reviewed by a team of independent award assessors who draw up a full report on their findings. This independent assessment gives an objective view of the organisation and therefore such a report is of infinite value to a company in pinpointing areas of strength which might be capitalised upon or identifying potential for improvement.

Two particular awards are of particular interest in this respect. In the USA, the Malcolm Baldrige National Quality Award was established by Act of Congress in 1987 (Reimann [110]). This award is based on TQM and two awards are made annually in each of three categories; manufacturing, service and small businesses. However, the awards are not automatically made to the top two applicants in each category; they are

only given when an organisation fully achieves the levels of excellence defined in the award. Thus, in the history of the Baldrige award to date, there has never been a year in which all the available awards have been granted. As a result, winners of the Malcolm Baldrige National Quality Award are always outstanding organisations. The Baldrige Award criteria framework is divided into four basic elements, across which seven judgement categories are defined. The first element is the "Driver" and is concerned with the way senior executives show leadership involve themselves with the creation and guidance of programmes to encourage a culture of quality excellence and customer focus. In the second element, "System", there are four areas of interest; information and analysis, strategic quality planning, human resource development and management, and finally, management of process quality. The third element is "Measures of Progress". This examines how the company carries out its business and considers quality and operational results which encompasses product and service quality, internal quality and productivity, and supplier quality. Element four is "Goal" which addresses customer focus and satisfaction; that is how the company interacts with its customer base. This element encourages proactive partnerships between the organisation and its customers. It may be judged both from a purely company viewpoint and relative to the performance of significant competitors.

In 1992, the European Foundation for Quality (EFQM) launched the European Quality Award (EQA). Its purpose is very similar to that of Baldrige, although the European TQM model, which is used to guide the assessment process, is somewhat different. It is divided into two elements. The first is "Enablers"; why, what, how and to what

extent the company does particular type of thing. This contains leadership, people management, policy and strategy, resources, and processes. The second is "Results" which measures the effects created by the Enablers. It contains people satisfaction, customer satisfaction, impact of society, and business results.

Chapter 4

Total Quality Management

4.1 Introduction

The concept of Total Quality Management (TQM) requires that all activities within an organisation, whether directly related to production or not, should be monitored with a view to improving their quality. The single most important feature of TQM is the attitude of the individual employee to quality, for without full employee commitment long-term quality improvement is not achievable. This must start from top management and permeate throughout all levels of the organisation and will include many people who would not normally consider themselves to have any influence on product quality (for example, ancillary, secretarial and catering staff). It is necessary to establish a company wide quality ethos to help such people understand that the standard of their work affects those more directly involved in product manufacture, and thus influences how well they carry out their task in the production process. The reasoning behind this concept and methods used to facilitate implementation are described by Feigenbaum [37] and Ishikawa [58].

The driving force behind TQM is management. This may seem to be stating the obvious, but often senior managers view TQM as a programme for the workers in which they have no part to play. In reality nothing could be further from the truth. Management must determine policy and establish company standards and work practices for quality which are allied to the company's business goal. They must provide

leadership to initiate improvement, examine company practices and procedures, and, where necessary, change things to facilitate better communication, coordinate quality activities and make available the requisite resources. In addition, it is management's responsibility to monitor successes and failures, and to support the ongoing development of the quality improvement programme. Therefore, it can be seen that management's role is the establishment and maintenance of an infrastructure suitable to fully support all of the disparate elements which must combine to make TQM work.

Having stated that any organisation operating under TQM will consider every activity, directly production related or otherwise, to have an effect on quality, it follows that data concerning all these activities must be collected and analysed, so that problems can be detected, their root cause identified, corrective action determined and initiated and subsequently monitored.

Thus, for TQM to be really effective, both management and staff require access to a wide variety of data. However, committed employees can only do so much; eventually the inherent limitations in the flow of information within an organisation dependent on paper-based data storage will become a brake on the quality improvement process. The large physical volume of quality data arising from product and process quality control causes physical storage problems, and the difficulty of accessing the data makes extracting information from paper records a high cost activity which precludes effective analysis of the data; thus undermining the effort put into data collection. Therefore, in order to be effective, TQM requires some form of computerised data storage and

analysis. Furthermore, to maintain a competitive edge, a company must be able to respond quickly to customer requirements, not only for new or modified products, but also in improving quality levels. This situation is discussed by Keane [66], who examines the shortcomings of non-computerised quality data handling, and the benefits which accrue from computerisation. Also Caine et al [12] describe the factors which led their company to implement a computer based quality system within their organisation. It is to address this problem that this work has been undertaken.

4.2 Management Information Systems

The effective management of any organisation, whether large or small, depends upon the use of management information. Such information provides evidence of the functioning of the system being managed, so that areas where corrective action must be taken may be identified, the success of previous actions can be monitored, and that outstandingly good areas may be highlighted for reward and/or study to identify beneficial influences so that they may be applied elsewhere.

The form of management information required varies according to the management level for which it is intended, so that top management normally need only highly summarised information concerning the entire operation, while middle management need considerably more detail, but only about their own area of responsibility.

Within a manufacturing company the management information system (MIS) will be

composed of a number of specialised sub-systems, each with its own well defined functional responsibility. The traditional functional decomposition of MIS elements results in a set of well defined sub-systems with minimal linkages between them. This reflects the quite rigid sectionalization found in many companies which frequently leads to adversarial relationships between departments, say for example, production and design. The effects of this type of inter-departmental relationship become all too obvious when there is a quality problem to be investigated. Each department attempts to justify its own actions by assigning blame to other departments. An important part of the process of developing an effective TQM system is the development of a community spirit where all departments (and all staff) work together for the benefit of the organisation as a whole, rather than just in the interest of their own department. It is also necessary that all understand the constraints and objectives of each part of the organisation so that possible repercussions arising from proposed actions may be gauged and planned for. The importance of this type of attitude change in the success of a quality system is emphasised by Ishikawa [58].

In a similar way, it can be seen that the co-operative approach required in the investigation of quality problems must be supported by the provision of management information from many, or indeed all, of the independent MIS sub-systems which serve the various functional areas within the organisation. These sub-systems may well have little in common in terms of data held, nomenclature identifying that data, system architecture, or even type of host hardware. Because of this wide-ranging disparity, it is difficult to construct management reports which cross functional boundaries. Thus

there is a need for a common access mechanism to obtain and integrate data from these disparate sources.

Another thorny problem in the structuring of MIS for manufacturing is the determination of the correct functional location of quality data. A simplistic solution is that quality is a production issue and that therefore there should be a quality module associated with the production MIS. Similarly, it can be said that quality is a design issue because quality means conformance to requirements, and the conformance tolerances are set during design. Likewise, it may be argued that quality should be assigned to marketing, because it is up to the marketing section to determine what the customer requires. In fact, all functional sub-systems of an MIS can be said to have a responsibility for some element of quality data. Thus management information concerning quality will be spread through all MIS sub-systems, and may, in some instances, be duplicated in several. For this reason it is difficult to obtain an overall picture of quality requirements and performance to inform the management of Total Quality. It is to address this difficulty that this work has been undertaken.

4.3 Supplier and Customer in Partnership

Effective TQM requires an involvement from suppliers of raw materials to the company, for a good internal quality programme can be undermined by unreliable delivery schedules and poor standards of incoming goods quality. A major source of supplier quality problems is poor communications between buyer and vendor. If the

supplier has not been able to obtain a clear, unambiguous statement describing the goods or services which he is expected to supply, there is a strong possibility that he will not be able to satisfy reliably his customer's expectations. It is therefore essential that a close relationship be maintained between customer and supplier, so that customer requirements can be clearly understood, and any problems can be discussed so that a mutually agreeable solution may be found. In addition to reducing supplier quality problems, a good customer/supplier dialogue will provide the supplier with extra information for production planning which may lead to the reduction of lead times, thus allowing both customer and supplier to reduce stock levels. To this end computerised systems are already being introduced in the automotive sector to improve data exchange between vendor and supplier.

This idea is strongly supported by Deming, who emphasises that the final customer sees only the company from which the product has been purchased, and assigns any deficiencies in the product to that company, wherever in the supply chain the problem was actually introduced. Thus it is vital that companies build strong relationships with their suppliers so that they can be as sure of supplier quality as in-house quality.

4.4 Just-In-Time Production Management

The concept of Just-in-Time (JIT) is that raw materials and parts should only be bought in or manufactured in small quantities just before they are needed as an input to the manufacturing process (Finch and Cox [40], Lascelles and Dale [76]). A company

operating JIT will extrapolate forward its raw material needs over a short time frame (typically between 1 day and 1 week) and will order only enough to maintain production for that period. This results in minimisation of inventory and thus reduces costs (Ansari and Modarress [1]) This calls for frequent, small deliveries from its suppliers, combined with a high degree of reliance upon the suppliers not letting the company down by late delivery or poor product quality. Thus the process is fed directly by its suppliers (whether internal or external) rather than from stock held in expectation of future need. This policy contrasts with the traditional practice of extrapolating the raw material needs of the process over the next few months (this may be anything from 3 to 12 months) and purchasing in bulk to satisfy the anticipated requirements of the process.

For JIT to be successful, either in the company to company supply chain, or internally in the process to process chain, it is vital that goods are delivered on time (neither early nor late), and that all the items supplied are useable, because late delivery or rejection of items will quickly halt the process. Therefore, in order to operate under JIT, quality levels must be improved (Pennucci [105]), ideally to the point of "zero defects", both in regard to non-conformances and adherence to delivery schedules. Only when quality is firmly under control does it become possible to manufacture directly to order, i.e. Just in Time.

Additional savings can be made if the supplier can guarantee quality levels to a degree where incoming goods inspection is not necessary. Over a period of time customers

may establish the reliability of their suppliers, both in respect of quality and promptness of delivery, by monitoring their performance. Assessments of quality may also be obtained by carrying out periodic audits of the supplier's quality procedures in operation.

Rees [109] describes the problems encountered by one sub-contracting company as its customers moved to JIT, along with the steps taken to alleviate those problems. One worry identified by this company was their ability to satisfy ever shortening lead-times; for if one of their suppliers failed them, either by late delivery or poor quality, they would be forced to let their customer down. For a customer organisation working to JIT principles, such a failure could have far-reaching and damaging effects. This situation emphasises the importance of a close and supportive relationship between customer and supplier throughout the supply chain, for any weak link can cause the failure of the whole chain. Furthermore, there is a danger that the introduction of JIT by an organisation near to the end of the supply will result in increased inventory levels being maintained by suppliers earlier in the chain so that they can be confident of satisfying their customer's orders. This change does not reduce costs overall, but instead moves the burden nearer to the start of the supply chain. This problem can only be solved by suppliers and customers working in close collaboration.

4.5 Single Sourcing

Multi-source purchasing is based on the premise that the "best" supplier can be identified by the price of their goods. This is borne out by the well established practice of competitive tendering which continues to be employed despite much evidence that "cheaper" is not synonymous with "better".

Deming [30] points out that where the same product is being provided by a multiplicity of suppliers, variations will exist from supplier to supplier, even though all meet the stated specification. These variations will affect the customer's process and may, in extreme cases, preclude him from bringing his process under statistical control. For this reason, Deming recommends the companies move towards single sourcing for bought in goods. This does not mean having only one supplier to satisfy all the needs of the company, but rather, that an effort should be made to identify the best supplier for each item and to then establish a long term partnership with them (British Deming Association [10]).

4.6 Ship to Stock

Companies employing a Ship to Stock policy receive goods from their suppliers and transfer them straight into stock (or in organisations working to a Just In Time policy, straight onto the production line (Lubben [81])) without first subjecting them to incoming goods inspection. This policy requires complete confidence in the quality of the supplier's products and processes. The customer will carry out audits of the supplier

to ensure that proper quality assurance procedures are in place and are being followed. Products are accompanied by documentary evidence, such as SPC charts and certificates of conformance, to demonstrate that the proper quality control procedures have been followed to assure the quality of the product. This is required, for example, by Ford Motor Company.

The reasons for adopting Ship to Stock may be two-fold; firstly, there is a cost saving to the customer resulting from the lack of incoming goods inspection. Secondly, with some types of product such inspection and testing is not possible because of the characteristics of the product. In this latter situation, very close collaboration is necessary between customer and supplier, because to all intents and purposes, the supplier is being treated as an integral part of the customer's manufacturing process.

Chapter 5

Aims and Objectives

5.1 Introduction

As can be seen from the preceding chapters, it is possible to apply a wide range of interpretations in the definition of a system for achieving quality in a manufacturing organisation; from inspection at the lowest end, through Quality Control and Quality Assurance, up to Total Quality Management. Given that the goal of this work is the investigation of how best to utilise computers to support the necessary data handling activities of a quality system, it is desirable to state at this point the interpretation of this author. It is her contention that, in order to achieve continuous quality improvement and hence full customer satisfaction, a quality system must be all embracing in the manner proposed under TQM. As a corollary of this definition, the issue of what is "quality data" and what is not, can be resolved: all data extant in an organisation, or indeed, in a supply chain, has potential to help in the process of ascertaining organisational strength or weakness in quality terms. Hence, for the purposes of this thesis, all data is "quality data". It could be argued that this definition is somewhat extreme, since there is a strong school of thought which states that one should not seek to produce quality levels which exceed the customer's requirement, however, the teachings of Deming [30], now widely adopted in Japan, present another view; that only the best possible is good enough. It is this latter stance that this author supports, for, despite recession, Japanese manufacturers continue to increase their market share at the expense of their competitors in Europe and the USA, by consistently providing better

products at a lower price, where, in this instance, price takes into account not only the purchase cost, but also includes maintenance and running costs throughout the life of the product. Furthermore, where consumers become richer, there is an tendency for cost to become less important relative to the desire for high quality. Thus high quality goods gain a market advantage over cheaper, but less good competitors.

It is the aim of this research to investigate the problems posed by the inadequacies of traditional methods of data storage for the purpose of long-term quality improvement, and to consider the ways in which information technology may be used to address these problems. Also of interest are any discrepancies between the theoretical facilities of a quality system (as drawn from the literature and discussed in the preceding chapters) and the actual facilities deemed necessary in practice by an example manufacturing company. Furthermore, it is necessary to consider the relationship between existing information systems (such as production planning and inventory) and the proposed quality information system. Whilst a case can be made for the quality system being the superior information system within an organisation, it is vital to realise the impact of such a solution upon companies wishing to adopt it. Such a dramatic change of direction in an organisation's information management system would be extremely costly to implement, and most definitely not without significant risks. It is therefore proposed that the quality information system be considered as the common ground upon which the integration of the presently separate systems which exist within an organisation may be based.

5.2 Requirements of the Quality Activity

The demand for quality data collection, storage and analysis arises from the requirements associated with quality monitoring, quality improvement and documentation pertaining to both product and quality system. These may be broken down into several subsections, so that quality monitoring requires such things as control over inspection procedures and calibration of measuring equipment. Similarly, quality improvement includes the strategic use of quality data to support and track the progress of a company in fulfilment of its business aims and strategy. This may be achieved in three areas:-

a) reactive quality improvement stimulated by identified failures found either in house (via inspection or SPC studies) or through customer complaints.

b) proactive quality improvement designed to increase the robustness of the process, and thus reduce the likelihood of quality failure. This includes both strategic quality improvement planning by management (for example, by staff training, regular preventive maintenance, or new plant), and local improvement (for example, by Quality Circles). Better customer satisfaction may be achieved by means of improved awareness of customer requirements, coupled with improvements in quality of design of both process and product which result from the use of techniques such as FMEA and experimental design.

c) focusing the combined efforts of supplier and customer in partnership to achieve

improved quality throughout the supply chain.

The provision of documentation must address the following issues:-

a) the need to produce information in some specified format to satisfy the documentary requirement of customers and standards. Additionally to demonstrate adherence to any relevant standards.

b) the need to be able to produce evidence that proper procedures have been followed in case of product liability prosecution.

c) the provision of a communications channel to allow the distribution of quality related information so that procedures may be monitored and areas where improvement may be needed can be identified. Also to monitor the effects of change on procedures and processes.

5.3 Summary of Quality Data Needs

Clearly the data needs of these tasks vary considerably, so that a solution suitable for one may not satisfy another. It is therefore necessary to establish the requirements of each of these quality activities in order to harmonize them into an integrated information gathering and enquiry system.

Reactive problem solving relies upon the ability to identify and examine quality information on a historical basis. In some circumstances (e.g. aircraft parts), there may be an additional need to trace other products from the same batch in case they too exhibit the reported fault. In this situation, it should also be possible to establish a link back to the source materials or raw materials if they may be the root cause of the problem, so that other batches in which those materials were used can also be traced. Combined with this is the need for control of the Corrective Action process (this is required by ISO 9000) to ensure that problems are corrected and that the effectiveness of the corrections applied are formally reviewed so that further action can be taken if necessary.

Quality improvement techniques such as SPC and Quality Circles are, for the most part, means of achieving control and improvement of quality on a local and immediate basis. As such, it is normally the case that the information required for analysis by these methods is obtainable locally. As has been discussed in chapter 2, automation in respect of SPC is available, although many quality practitioners have reservations about the advisability of fully automating SPC because of the potentially detrimental effects of reducing worker involvement and understanding. In the case of Quality Circles, where the data needs are very simple, it seems likely that only the facilitator would require access to a computerised information source, and that only infrequently.

However, whilst these methods are an important part of a company wide quality improvement programme, there is a need for strategic quality planning by management.

To be effective, this planning must be supported by a flexible, comprehensive information server which is able to supply data for investigative analysis and to keep track of the progress of strategic plans.

Quality of design is arguably more vital to the overall quality of the finished product than quality of manufacture. It is therefore necessary that designers have access to historical data pertaining to the performance of earlier similar products in the field, along with details of the capabilities of the processes used to produce them. Also of interest will be details of any available alternatives in process or product design. Additionally, with a view to establishing a more accurate understanding of customer requirements, the results of market research will be of use to the designer. This information may be combined with experimentation, utilising, for example, Taguchi methods in order to achieve robustness in both process and product.

With the increasing demand for manufacturers to satisfy company-specific, national and international standards, and the recent changes in Product Liability legislation, there is a need for an organisation to have documentary evidence of conformance to quality procedures both in all elements of manufacture and design.

As quality improvement programmes become established, the role of suppliers in the achievement of quality becomes more evident. There is a need for communication between customer and supplier as they begin to work together to achieve mutual satisfaction. There must be a clear understanding of the requirements of the customer

by the supplier. This may be attained by direct transfer of specifications from the customer's database to the supplier's. Further, evidence of conformance to those requirements may be passed back in a similar way. The interaction of a series of Integrated Quality Systems (IQS) through the supply chain is illustrated in Figure 5.1.

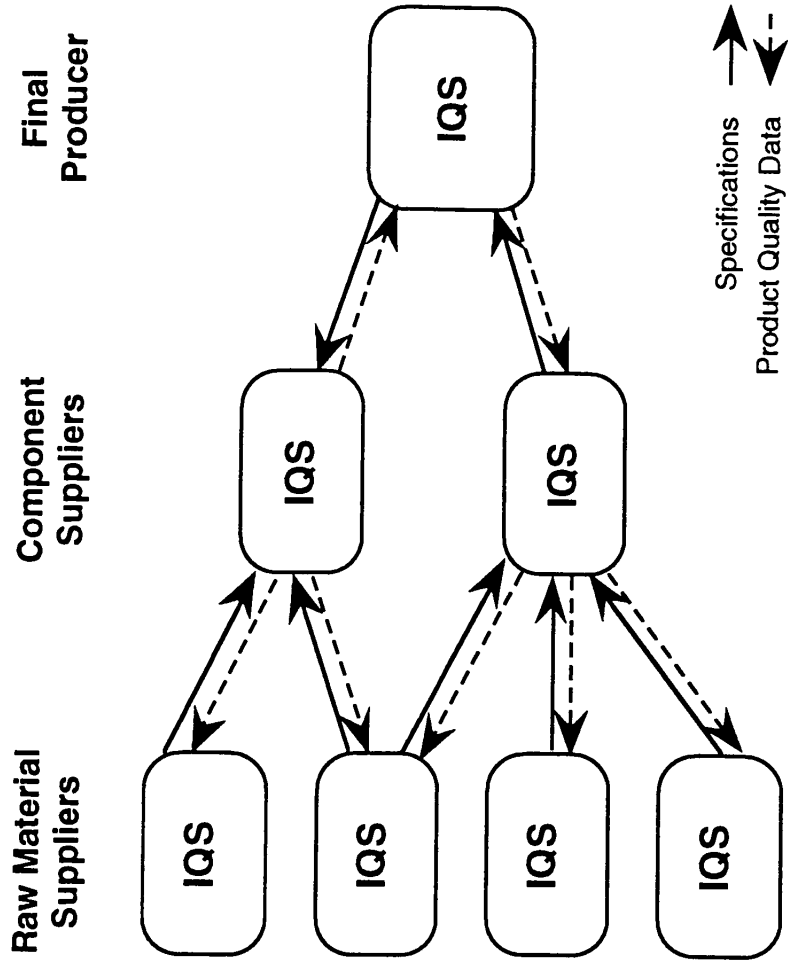


Figure 5.1: IQS Linkage through the Supply Chain

5.4 Integrating Quality Information

Bringing together the needs of the various quality related tasks considered above leads to the proposal that an integrated database of quality information should be set up. This database should have the ability to answer not only a set of standard, pre-defined queries, but also unforeseen, ad-hoc enquiries. Furthermore, that there is a requirement for links with other systems within the organisation (for example, production planning, clerical, CAD/CAM) to allow the relationships between quality problems and other factors to be examined.

It is first necessary to consider the nature of present management information systems. Within a manufacturing organisation there exist a number of independent data resources, each assigned to some specific function, and normally isolated from one another. These data resources may be of several types; firstly, purely paper based (i.e. traditional filing systems) although it should be noted that these may incorporate space saving devices such as storage of data on microfilm; secondly, simple microcomputer based systems servicing the needs of well defined, but strictly limited functional areas; and finally, site or company wide databases to support given organisational functions (for example, payroll or stock control).

The inherent nature of quality makes definition of what is quality data, and what is not, extremely difficult. Support can be found for both the stance that quality data simply means inspection results, and the much wider position taken by the Total Quality lobby that since quality is part of every activity, all data is quality data. Clearly these are the

two extremes, but the difficulty in resolving this question makes the design of an information system for quality improvement somewhat problematic, as does the issue of who has responsibility for obtaining and maintaining quality data, and who is to be allowed what degree of access to that data.

Consider the flow of an order through a company. When the salesman obtains an order it is registered by the financial administration system. Then production planning is told what has been ordered. At this stage, it may be necessary to bring in the design function if the product required is not already in the catalogue. Raw material availability must be checked and additional supplies ordered if necessary. The production run may then be scheduled, and at the defined time, machinery must be set up and manufacture undertaken. The finished goods will then be despatched to the customer, along with an invoice. The company financial system must then monitor that invoice to ensure it has been paid. Throughout all these activities there is a need for tasks to be done correctly to ensure the overall quality of the product and the administrative activities attendant upon its manufacture and sale. Thus data concerning all these tasks can be considered to be quality data. However, the functions identified in the preceding narrative also have a need to use the relevant data in order to carry out their assigned task. Hence there is a requirement for data sharing between functional areas and the quality system.

Since a given functional system (eg. production planning, design, procurement) has the most knowledge and experience of the operations which it controls, it is logical that it

should also take responsibility for quality in those operations. This follows from the findings of those who have investigated quality control in manufacturing processes and have pointed out that the person doing a particular job is the one who usually knows most about it, and therefore that person should be in control of quality for that job. Thus quality information may be held and utilised by individual functional systems, but must be combined from these separate sources to address cross-functional issues.

As has been discussed earlier, quality is a strategic activity which requires focused management involvement. In practice, it comprises three basic functional elements; prevention, cure and documentation. Quality Control may be considered to be the "cure" side, while continuous quality improvement can be identified with "prevention". The needs of prevention are rather different from those of cure, it is therefore necessary to ensure that the quality information system can satisfy both. Thus it must not only provide the means of detecting and identifying the root cause of quality failures ("cure"), but must also supply information to the planning process to allow quality to be built in to both product and process ("prevention"). Finally, it must provide evidence that proper procedures have been followed in order to satisfy contractual obligations and international standards.

The ACME project team likened the Central Quality Database to the keystone of an arch; the single element which transforms an unstable and inherently weak structure into a stable, very strong functional unit. In like manner, the Integrated Quality System can provide the necessary linkages to greatly enhance the usefulness and effectiveness

of data in a CIM organisation. This is shown in Figure 5.2 which is an extended version of an unpublished slide presented by the team at one of the ACME project's review meetings.

Thus, it is the purpose of this investigation to establish the core functionality of an integrated quality database and management information system, and to consider the practicality of implementing such a system in a manufacturing organisation.

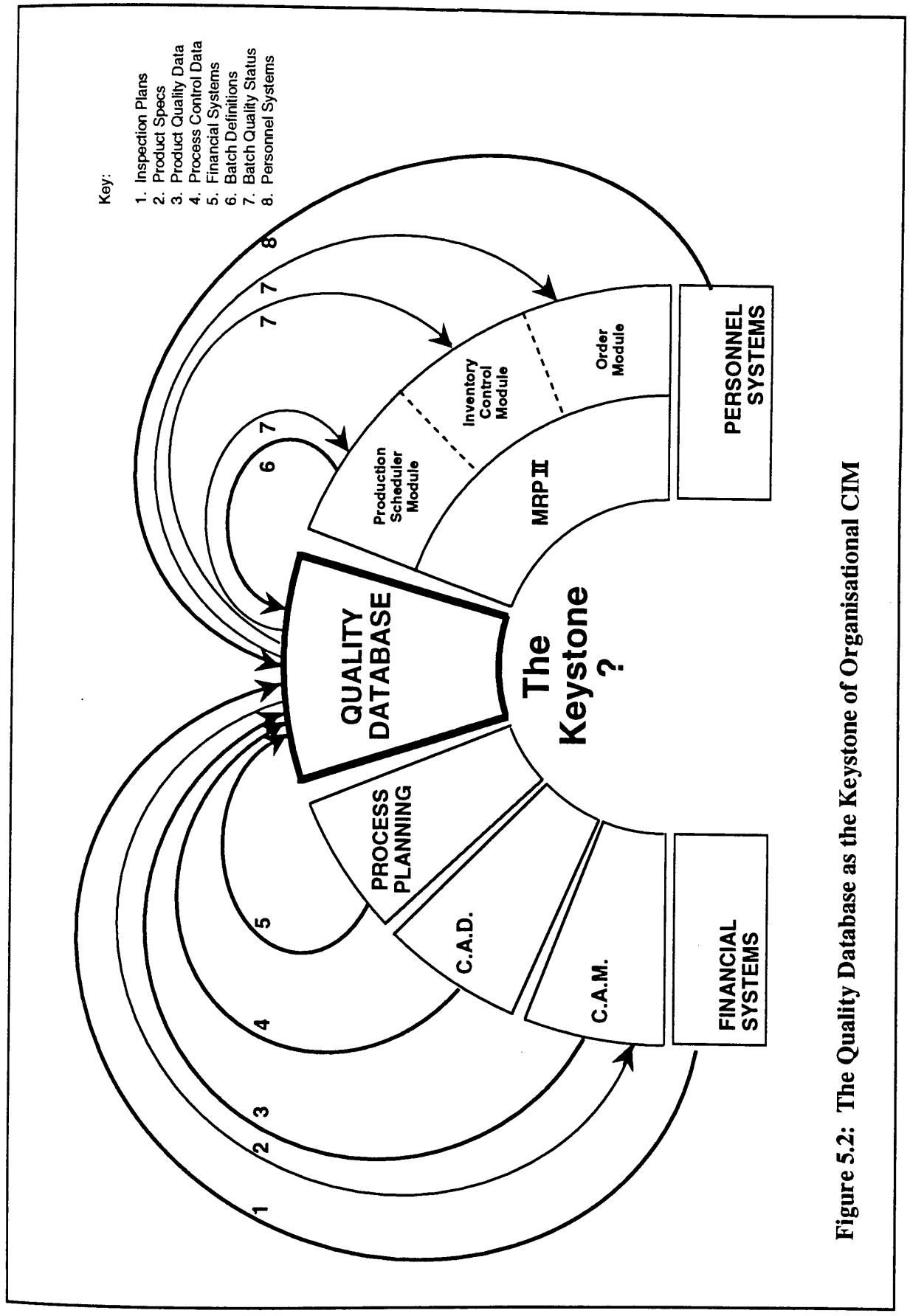


Figure 5.2: The Quality Database as the Keystone of Organisational CIM

Chapter 6

Specification Of The Integrated Quality System

6.1 Introduction

In BS 4778 the term "Quality System" is defined as:-

> *"The organisational structure, responsibilities, procedures, processes and resources for implementing quality management."*

It is proposed that such a system may be implemented by means of an Integrated Quality System (IQS) which utilises computer technology to provide the necessary linkage between the various free-standing elements of a manufacturing organisation, thus leading to effective data management and improved provision of management information for quality planning.

The IQS will have at its core a Central Quality Database (CQDB) which will be the controlling nexus of the interface between the IQS and other, existing information systems both within the organisation and throughout the supply chain.

It is further proposed that the IQS will not be limited in scope to the operation of a single organisation, but will provide the necessary mechanism for the provision of quality data integration throughout the entire supply chain. The Electronic Data Interchange (EDI) standard already provides a message standard to allow suppliers to

receive orders, design drawings and specification from their customers by electronic means, but for effective quality improvement throughout the supply chain, this must be supplemented with quality specifications and possibly test analysis code provided by a chain of IQS's linked via EDI. Conversely, in addition to their product, suppliers will submit to their customers all necessary evidence of conformance to both specification and the requisite quality assurance procedures. However, this will be done neither by exchange of paper documentation nor by electronic data transfer, but by providing access for the customer's information system into the relevant areas of the supplier's system. It will therefore be necessary for the IQS to include data access procedures which can be initiated by EDI messages, and which, in turn, can initiate new messages to other IQS's in the chain. Hence, the information flows throughout the whole supply chain may be integrated in a way similar to the internal data integration in a single organisation or site.

6.2 Integration With Existing Production Systems

The approach taken herein revolves around the stance that there should exist in an organisation an active information system focused on the assurance and management of quality in the manufacturing operation as a whole as a means of effectively implementing TQM in practice.

This differs from the position of earlier workers both in the type of solution proposed and in the scope of the solution. It was believed that quality standards such as BS 5750

could be satisfied without the introduction of a new information system specifically targeted on quality. Furthermore, BS 5750 tends to engender a belief that the goal to be achieved is to merely the satisfaction of quality standards by the maintenance, use and documentation of procedures and the possibility of a higher goal; that of everlasting improvement, as is the intent of TQM, may not be not considered. In practice however, this is not usually the case because the introduction of BS 5750 tends to result in the accumulation of more extensive records and a desire to carry out more analysis on those records. The difficulties associated with the flexible analysis of paper-based records result in a desire to move away from existing manual data collection and analysis, towards IT systems. Thus Baines and Hughes [3] consider the relationship between the previously separate functions of Production Control and Quality Assurance purely in the light of BS 5750. They suggest a possible outline for a quality information system which, they state, would satisfy BS 5750; this system being achieved by the extension of existing Production Control information systems. The information of interest being divided between data which is fairly static in nature (ie. calibration, quality training, quality audit, internal and external fault record, and quality costing), and more dynamic data concerned with active quality control activities and corrective action control. Furthermore, examination of Production control systems led Baines and Hughes to the conclusion that much of the dynamic quality data can be obtained from production control systems with only minor modification, although they do point out that analysis of this data for quality use would have to be carried out manually or by means of some custom software. Their proposed extensions to the "typical" production control system are listed in their paper. Beyond this proposal, Suresh and Meredith

[127] consider factory automation and suggest a procedure for the gradual, incremental, integration of quality assurance information into existing manufacturing information systems used in the production stage. They go on to consider how extension of quality data capture, both upstream and downstream might produce new opportunities for increasing revenue. In contrast to this, Turnbull et al [139] consider the relationship between JIT operating in combination with TQC and Information systems in the UK automotive industry. Their key conclusions revolve around the need for local ownership of data and lateral flow of information rather than the more normal vertical flow.

The system described herein moves on from these positions by focusing on the need for a purpose-built quality information system devoted, not merely to the satisfaction of BS 5750, or the support of JIT, but to the achievement of true TQM; a goal which requires full and flexible access to all kinds of data generated throughout the many and varied operations of an organisation.

6.3 Functional Requirement for a Generic IQS

The views of the various quality gurus were combined with the requirements of the relevant standard to produce a theoretical model of the facilities that should be provided by the "ideal" quality system; the theoretical basis for this was discussed in chapters 2, 3 and 4. Also considered were the capabilities of existing quality data acquisition and management packages (see appendix 1) and the desires expressed at presentations by quality assurance managers and consultants.

This allowed a formal Functional Requirement for a generic integrated quality system to be drawn up. This brief statement provided a clear set of goals to be satisfied by the integrated quality system and gave an indication of the range of data which the central quality database might be expected to hold.

The Generic IQS shall provide data support for quality related activities across the entire organisation through the provision of the following functionality.

1. To maintain product inspection specifications and procedures. Also to record details of inspection methods and procedures specific to particular processes. Further, to provide a control on the inspection function by controlling access to, and updating of this information.

2. To obtain and collate all information on product and process quality, and capability of appropriate aspects of the manufacturing function. This should include historical data concerning the basis for decisions taken during the design of both product and process. Additionally, records should be maintained for problem solving activities undertaken at all stages of organisational lifecycle, including not only the manufacturing elements, but also customer related processes such as determination of requirements, after sales service and maintenance, and product disposal.

3. Where possible, to exercise direct real-time control over the production process.

This goal may be achieved as a consequence of the automation of collection, collation and analysis of quality data during product manufacture.

4. To provide management with decision support information on all aspects of quality by means of a set of standard reports, with additional provision being made for responses to ad-hoc queries, including the definition of new reports.

5. To maintain quality records in conformance to appropriate quality systems standards (eg. BS 5750/ISO 9000, AQAP), and as may be required by law (or for defence in case of prosecution).

6. To provide well defined interfaces with existing systems (such as production scheduling, design, order processing and personnel) to facilitate future integration.

7. To maintain records of other items which have relevance in the light of a policy of Total Quality Management. For example, quality levels of incoming goods and services, vendor rating and equipment calibration.

When a company plans the development of a new quality data management system, careful consideration should be given to how the seven elements of this general functional requirement can be related to the way the company operates, its type of product, and the needs of its market niche. This targeted investigation will expedite the

production of a customised design for the proposed system, while protecting against the omission of significant functionality.

6.4 CQDB Functionality

The CQDB is the principal repository for quality data within the IQS. It is not, however, the only one, as it is considered that, where required data is already held, it should not be duplicated, but that gateway mechanisms should be provided to facilitate access to it through the IQS. In functional terms it is envisaged that the role of the CQDB within the Integrated Quality System (IQS) shall be as follows:-

6.4.1 Quality System Maintenance

To maintain control over the issue and update of Quality procedures and to produce documentation as evidence of the correct operation of those procedures in practice. Also to provide swift and easy access to those procedures and documents.

6.4.2 Product and Process Design

To provide input to the design of both product and process so that both may be made as robust (in the quality sense) as possible given the knowledge and experience of those involved. This may include such activities as Designed Experiments (possibly Taguchi methods), FMEA, Reliability testing and the estimating and tendering process, and will require input from historical quality data. Also to identify any legislation or standards which are directly applicable to either product or process.

6.4.3 Creation and Maintenance of Inspection Plans and Specifications

To maintain inspection plans and specifications for all products (including facilities for proving process capability), with these plans and specifications being derived via a link with the CAD/CAM system. Additionally, to record details of any inspection methods or procedures specific to particular processes. To provide these (on instruction from the production scheduling system) to inspection facilities whether manual, computer assisted or fully automatic, in a form such that they may be used by external inspection control software (such as third party SPC packages).

6.4.4 Recording of Inspection Results

To receive from inspection stations the results which have been collected during the batch run (either in full or summary form). The CQDB shall take no part in real-time control of the process at the level of individual production machines, although it is possible that troublesome interactions between a group of machines, each causing no problems on its own, might be detected as a result of the data integration occurring in the CQDB. In terms of the manufacturing cycle as a whole, control may be exercised as a result of feedback from the CQDB (for example, at the design stage data should be available concerning customer reaction to previous related products, maintenance experiences and so on).

6.4.5 Archiving of Historical Data

To provide access to a variety of historical data for the provision of quality data for customers, and for use in the quality improvement programme. The data held will

include, but not be limited to, inspection results, records of product failure in use (for example, drawn from customer complaints or the findings of staff engaged in servicing the product in the field), product, process and documentation modifications during production lifecycle.

6.4.6 Corrective Action

To maintain control over the Corrective Action procedure as required by BS 5750. Furthermore to provide a historical record of requests for Corrective Action, along with details of the actions taken and the resultant effects. It is desirable that this should include cost information.

6.4.7 Customer Complaints

To record details of Customer complaints and monitor the resolution of each complaint so as to minimise the effect on the customer as far as possible, and then to prevent repetition of the problem by means of the corrective action procedure described above.

6.4.8 Vendor Monitoring

To monitor the performance of vendors (for example, delivery schedules, quality failures in supplied goods, records of audits of vendor's of quality systems). In a fully functional IQS this might include direct links to the supplier's IQS.

6.4.9 Training

To monitor the progress of individual members of staff as they are subject to training.

To ensure that staff receive training suitable to their job function, as defined in company standard training plans, and as set out in relevant standards or legislation. Further, that staff are not assigned to tasks for which they have not had the requisite training or qualification. This may be extended to the recruitment of new staff, and to the planning of holidays and absences for training or off-site work so that suitable cover is always available.

6.4.10 Calibration Monitoring and Records

To provide evidence that all necessary equipment calibration has been performed at the required intervals, by suitably qualified persons and with the authority of the appropriate regulatory bodies. Also to allow the initiation of recalibration activities as they fall due.

6.4.11 Safety and Reliability

To plan and design all activities, processes and products with a view to assuring the safety of all persons involved, whether users, purchasers or those in the vicinity during use. It is important to note that this does not deal only with product safety, but also with the safety of employees of the producing organisation, and may be extended to cover the safe disposal of both the product itself and any by-product of the manufacturing process. This part of the system will include records of the application of relevant legislation and standards; records of safety and reliability planning activities in design, ie. FMEA, fault tree analysis and/or design reviews; testing plans and results; certification of bought in components (note: this may be via access to a

supplier's IQS). These records might also be of value in case of prosecution under the Product Liability or Health and Safety at Work (eg. COSHH) legislation.

6.4.12 Quality Cost Records

To monitor the cost of quality assurance and quality improvement activities and to record the cost of quality failure so as to provide financial justification for expenditure on quality improvement. Changes in Quality Cost levels over a period may also be used as a metric for both organisational quality health and to judge the effectiveness of improvement activities.

6.5 Additional Requirements

Access to the IQS will be required by a wide variety of users across all departments of organisational activity. It must therefore be easy to use, whilst containing safeguards against unauthorised or accidental alteration of the data. Users must be provided with the ability to undertake investigative analysis on any data elements combined in many unpredictable ways. In parallel with user initiated activities, the IQS must have the ability to carry out a selection of predefined tasks at the appropriate times without user intervention.

Finally, the underlying condition for the CQDB must be considered; that is the question of non-duplication of data between the CQDB and other information systems holding quality relevant data. In order for the IQS to provide the service specified for it in the provision of all the information required to achieve properly informed decision making

in a TQM environment, it is mandatory that the IQS should have access to all types of quality data, wherever it resides. Thus, it is necessary that a dynamic directory be maintained identifying all quality data available in the organisation, and by which system it is held. For convenience, throughout this thesis this directory will be referred to as the "Yellow Pages", although it should be noted that this name is a trademark of British Telecommunications plc, who publish a services directory under it.

Chapter 7

Quality System Requirements at the Test Site

7.1 Introduction

Between 1987 and 1989, a study of operations at a site of Du Pont Electronics was carried out under the auspices of a three year research project funded jointly by the ACME directorate of the SERC and Du Pont Electronics (Grant Number GR/E 04318). This study was focused on the quality function and its relationship with the other manufacturing activities. The aim of this project, entitled "Integrated Systems of Quality Control" was to develop quality related methodologies and technologies compatible with the requirements of 1990 and beyond and, from that base, to implement an integrated system of total quality control to improve service to the customer and reduce the overall costs of quality in line with a process of continuous improvement.

It is important to recognise that the goals of the ACME project were considerably less broad that those defined for the IQS. Whereas the ACME project focused on Total Quality Control, the remit of the IQS, as defined in this thesis, is the full support of Total Quality Management. Hence, a number of additional functionalities are required.

The method followed during this research was as follows:-

The need for an integrated data storage and access system was identified from the

literature (see chapters 1, 2, 3 and 4). The studies of the Test Site undertaken by Tannock [131] and Harwood [51] were used as a basis for a prototype integrated quality system for the test site, in particular the Inspection Control module. This work also helped to establish, in broad terms, the role of the CQDB within the IQS. To their work were added a number of other requirements which had been identified in the first phase of the study (the literature survey).

Once this set of requirements had been synthesised into a consistent whole, a functional requirement for the system was drawn up. This was then used as the basis of the design of a working prototype which was intended both to test the feasibility of implementation of an integrated quality database, and to elicit comment from potential users (such as staff from the test site, as well as from other organisations). The following chapters describe in more detail the design, implementation and analysis of this system.

7.2 Du Pont Electronics - A Case Study

The Du Pont Electronics case study was undertaken to allow a comparison between the theoretical requirements of a quality system, as identified from the literature, and the practical needs of a working quality system in a company which had a commitment to quality.

7.2.1 The Test Site

The test site selected for this project was a small, fairly new site of a large international

company, Du Pont De Nemours. The Du Pont organisation is sub-divided into groups according to the types of product manufactured (eg. chemicals, electronics). The test site was a member of the Electronics group, which had three sites in Europe; at 's-Hertogenbosch in the Netherlands, Besançon in France, and Yate on the outskirts of Bristol in England. The Bristol site was within easy reach of the project team's base, thus allowing frequent visits for discussions with staff.

7.3 Analysis Of The Existing System

The existing system was examined from two quite different viewpoints, that of quality systems, using IDef0 as the modelling tool, (Tannock [131]), and that of management and operations, using the cybernetic modelling approach (Harwood [51]). These analyses were used as modifiers for the theoretical IQS functional requirement described in chapter 6 and thus controlled the design of the prototype IQS.

Firstly, it was necessary to gain an understanding of company operations as a whole so that the context within which the IQS was to operate could be established. This led to the definition of boundaries of influence of the proposed IQS, thus restricting the scope of required further analysis. The interfaces which would be necessary between the CQDB and existing systems within the company could be roughly determined by studying the gross dataflows within the company. All this early work was based on Harwood's cybernetic model.

Details of how the existing quality system functioned were provided by Tannock's IDef0 model. This model reflects Tannock's specialism; that is quality assurance rather than IT, and for that reason was a very thorough analysis of the situation from a quality assurance viewpoint, However, for use in the design of an computer system for the support of the whole gamut of quality activities, a number of significant questions were left unanswered. It was therefore necessary to use more traditional analysis methods to integrate the two existing models, and then fill in the gaps to establish a complete model of the dataflows in the existing system.

The existing quality system operated effectively, even though the full potential of the available data was not exploited in the provision of reports and indicators of quality levels.

At the Du Pont site, a limited amount of computerisation had already taken place with the development of several free-standing systems on microcomputers. These provided for recording and presenting Parts Per Million figures (PPM), customer complaint records, and monitoring of equipment calibration. Plans were in hand for the addition of further systems to handle supplier records generated from incoming goods inspection and vendor rating (Savage and Tannock [114]).

While this partial computerisation was a worthwhile step forward from the earlier, wholly paper-based system, its effectiveness was limited by the very stand-alone nature that had made these small systems possible.

In contrast with the very limited exploitation of computers in the quality system, several major software systems were in place for other business functions. The Berg On-Line system (BOLS) handled all orders received by the Electronics group from Du Pont sales outlets throughout Europe. The MAS-H database was used to control production at the various factories in the group so as to satisfy customer orders transmitted from BOLS. Both of these systems included centralised databases which could be accessed by any site in the group, thus ensuring data consistency.

7.4 The Quality System Desiderata

After the analysis of the existing system had been completed, work commenced on the development of a functional specification for the integrated quality database. Initially a list of desirable features was constructed. This was an imaginative attempt (which may be likened to brainstorming) to cover all the things the system might possibly be required to do, however unlikely. At this stage of the system definition, it was considered important to have input from a wide range of prospective users of the proposed system. As a catalyst, an initial list, based on the set of functions provided by the existing system, was produced by this author and circulated to interested parties. This was used as a starting point for discussions with other members of the project team and with a group of staff performing a variety of roles at the Du Pont site.

A very wide range of suggested system functions resulted from this exercise. This gave a clear indication of the likely scope and sphere of influence of the total system: a

factor which was considered vital to the success of the project in the long term.

Some of the items suggested were clearly of only minor importance in the overall project plan while, in complete contrast, a number of other items stood out as being absolutely vital. These later formed the basis of the formal functional requirement for the integrated quality database. Meanwhile, the remaining items were roughly prioritised for inclusion in the later stages of the project. The identification of several comparatively unimportant ideas in the desiderata did not detract from the benefits accruing from the wider view provided by their incorporation into the development plan at the inception of the project. Interestingly, several items which were identified in the literature as standard parts of a quality system were absent from the desiderata. These will be discussed later in this chapter.

Additional functional requirements always come to light after a system has been in use for some while - this is a fact of life in systems design and implementation. On the basis of this project, it does seem that the pseudo-brainstorming approach used to develop the desiderata significantly reduced the number and importance of these 'after thought' items relative to the analyst's expectations. The overall picture provided by the desiderata helped to guard against overly restrictive decisions in the early stages of system design and implementation, thus reducing the problems inherent in expanding the scope of the software at a later date.

The quality system desiderata was a rather chatty, informal document, mainly because

its purpose was to stimulate discussion among a group of users who were lacking in familiarity with computers. It was liberally sprinkled with notes and helpful comments which helped to clarify the suggestions in the context of the situation and practices at the pilot site. The items proposed were not sequenced in any particular order and the document as a whole may be looked upon as the result of a sort of written brainstorming session. The full range of items identified and discussed in the pilot site Desiderata are shown below.

7.4.1 Desiderata for an Integrated Quality System

1. Records of customer complaints received, corrective action taken, and also an estimate of the loss incurred as a result of the complaint. A very simple stand-alone DBaseIII system already existed which could be used as a prototype for this function.

2. Maintenance and calibration schedules and requirements, initially for all inspection equipment, but with a view to extending these records to cover all other equipment. A menu-driven, stand-alone system was already in operation and working well. It seemed possible that this software could be incorporated into the integrated quality database.

3. Provision for manual data entry of product, batch and sample variable and attribute quality data. Such data entry would normally be carried out in

production areas and goods inward inspection areas.

4. Provision for data entry from automatic measuring equipment (eg. a vision system) of batch quality data in variable and attribute form. For example, batch statistics for a number of dimensions, or proportion of sample defective or rejected.

5. Provision of a standard user interface for many commonly needed data queries. A menu-driven approach to this facility would probably be the easiest for non-computerate users to operate. Some examples of possible enquiries might be:-

    a) batch quality levels by individual batch.

    b) quality levels by part number, whole plant, part type or customer over some stated timeframe.

6. Pre-defined set of standard, tabular management reports presenting the results of certain regular queries.

7. Provision of an interface between the quality database and the existing production planning system (MAS-H).

8. Statistical analysis techniques such as SPC and PPM to be included as standard using an interface to some commercial statistical package external to the

database. The algorithms used in the package must be verified for correctness.

9. Facilities must be provided to answer non-standard, ad-hoc queries posed by users who may not be very computer literate.

10. Simple and quick generation of non-standard, ad-hoc reports, both tabular and graphical, must be available to users.

11. Integration between mini/mainframe and process supervisory microcomputers and terminals in both production areas and goods inward inspection. Suitable communications protocols must be investigated.

12. Inclusion of vendor rating information such as incoming product quality measures and reliability of order delivery schedules.

13. Extension throughout all activities of the plant, not only those directly concerned with production (ie. TQM).

14. Keeping track of orders received, lead times required prior to shipment, promised delivery dates and actual delivery dates.

15. Control of the issue of invoices and purchase orders. This function may be achieved by means of an interface to existing DP systems.

16. Keeping track of issues and updates to drawings and product inspection lists (PILS). Ensuring that all old versions are recalled when an updated drawing is issued (ie. document control).

17. Communication between the CAD system and the quality database to allow transfer of dimensional information for inspection plans.

18. Records of operator skills - who is competent to set up or operate each machine or process. Also skills of other grades.

19. Records of what training each member of staff has received. Provision for comparison of training actually received against one of a set of standard training plans to be defined according to job function.

20. Holiday planning - will a trained reserve operator be available to provide cover? This could also be of use when a member of staff reports certified sickness or when an off-site visit is planned (eg. for attending a training course). If no backup is available, suitable contract staff may need be employed to cover, alternatively work may be re-scheduled to circumvent the problem.

21. "What-if" facilities for exploring options for plant and process planning. This could be provided via a link to a spreadsheet.

22. Access to public databases (eg. Prestel) should be possible from the quality database (although the group of users asked for this capability, none of them seemed sure when they would actually need to use it in practice).

23. Provision of an interface to the existing Electronic Mail facility in operation on the site. This facility was used extensively for communication both inside the site, and between sites in the organisation; although telephones, telex and facsimile services were available, most traffic was carried via the Electronic Mail facility, thus reducing overheads associated with high volumes of paperwork.

24. Interface to a desk-top publishing system for secretarial work and inter-departmental management reports. This should allow the inclusion of drawings from the CAD system to permit discussion of proposed new product designs, and the production of sales literature.

25. Provision of windowing facilities to allow comparison of the results of several queries.

26. Use of barcode readers for easy data entry of such things as product identification or defect type. This form of data entry would reduce errors caused by mis-keying of data.

27. Ability to compare process data across various sites. Initially, this may only be feasible by indirect means (ie. printed reports posted between sites), however, in the long term it should be possible to provide direct access to the database, probably by means of telephone links or Electronic Mail.

28. Data structure must be flexible to enable easy modification to meet future changes in system requirements.

29. Provision of a teach-yourself training package to complement a straightforward user interface so that users need to be neither highly computer literate, nor necessarily frequent users.

30. Facilities for the calculation and analysis of process and machine capability.

31. Contract staff records. These might include details of experience and past contracts with the company. This was a significant issue for the test site because of a company policy which resulted in extensive use of contract staff to supplement a very small core team of permanent staff.

32. Provision for the analysis and presentation of quality costs to indicate the impact of non-conformance versus the cost of implementing corrective action.

33. Graphical output to be provided for many standard queries. This would greatly

aid users in perceiving trends in the data which would not be easy to detect in information presented in tabular form.

34. Records of safety incidents with full enquiry and reporting facilities, including graphical displays. This could include severity of incident, cost in lost man-hours/days and corrective action taken. Safety was a very high profile issue at the test site, with a prominent, permanent display in the reception area showing number and type of incidents for the current year, along with the elapsed time since the last incident. It is notable that off-the-job accidents involving employees were also recorded.

7.4.2 Analysis of the Desiderata

Analysis of the integrated quality system Desiderata constructed from the perceived needs of the subject site gives rise to some interesting questions, especially when considered in the light of main-stream quality theory and practice (as discussed in chapters 2, 3 and 4 of this thesis).

The use of statistical tools received some mention (items 8 and 30), but this seemed to be triggered by a feeling that statistical analysis was "supposed" to be part of a "proper" quality system, rather than because it was perceived to be a vital element of their quality procedures. The only statistical analysis actually taking place in the existing system was the calculation of PPM from the results of final inspection.

Although there had been an attempt to introduce SPC into the site, this had failed due to a poorly thought out training plan.

Although some mention was made of corrective action recording (items 1, 32 and 34), this was not in the form of a true corrective action control system as required by ISO 9000. At the time of the study, there was no such system (manual or otherwise) in operation at the site. However, some 18 months after the construction of the Desiderata, a manual system was designed by this author and staff from the test site in anticipation of assessment for ISO 9000. This is discussed in more depth in later chapters. Unfortunately, less than a month before the launch of the new manual system, massive organisational changes within the parent company resulted in the complete shut down of production at the site, and so the launch was cancelled.

No reference was made to the use of any form of experimental design or reliability analysis; nor was there any mention of design quality assurance (eg. techniques such as FMEA).

Quality Circles were not in existence at the site, however the somewhat unusual management structure of self-managing teams responsible for the smooth running of a given functional area, provided many of the advantages of the Circle movement, although there was a strong tendency for firefighting to interfere with forward-looking investigation for planned improvement.

The Desiderata provided evidence of much interest in the monitoring and interfacing of functions outside the remit of the existing quality system. For example, personnel issues (items 18, 19, 20 and 31), document control (item 16), business and planning functions (items 14, 15, 21, 22, 23 and 24) and vendor performance monitoring (item 12).

A further issue which came to light over a year after the development of the Desiderata was the possibility of data exchange between customer and supplier. The factors which led to the identification of this requirement were twofold; firstly, electronic data exchange of specification details from customer to supplier would be faster and more accurate, and secondly, provision of quality assurance data relevant to the supplied product in electronic form by the supplier would allow its incorporation in the customer's quality system. This view is consistent with the findings of other organisations in a variety of industrial sectors. This concept can be extended to allow customers and suppliers direct access into the integrated quality system, although it then poses some quite complex security questions, both in respect of ensuring data consistency and accuracy, and the protection of company confidential information, whether it be concerning the central company, or the interest of different suppliers or customers.

7.4.3 Further Design Questions

Certain of the above items gave rise to questions which might have a great impact if

the integrated quality system was to be adopted as a company-wide quality assurance aid, fully integrated into all parts of the international parent organisation of the pilot site. These questions also require consideration in terms of the definition of requirements for a generic integrated quality system to support quality activities in European engineering companies.

For example, the question of language. The test site is in England, so most of the staff were native English speakers, therefore the prototype was planned to use only English. In the future however, information from the database should be made available to other sites in the same group (item 27 above). Since these are in France and the Netherlands respectively, the issue of whether they should receive reports only in English or have the option of a set of reports in their own languages must be considered. Furthermore, if the other sites are to have access to the database, should a multi-language user interface be provided? As an extra complication, it must be remembered that all the textual data held in the system is likely to be in English. While the task of setting up multi-language reports and interfaces is quite lengthy, it is not really difficult because of the essentially fixed nature of these elements of the system. The same is not true of translation of the data, which is, by definition, variable and unpredictable in all but underlying format. In addition, it would be necessary to produce translated versions of the training package (item 29 above). A further consideration must be the implications of the use of different base alphabets according to language. For example, French, German and English use basically the same alphabet (although there are small variations because of accents), however, Greek and Russian both use quite markedly different

characters, and of course the problems becomes even worse when one considers the Chinese ideogramatic languages. The solution of this problem requires not only software modification, but also the use of special hardware. Fortunately, it is by no means clear that there is a real-world requirement for systems which span, not only different languages, but different character sets. Beyond the identification of this matter as a possible issue for the generic IQS to address, no further consideration has been given in this work to possible solutions, as this was felt to be outside the boundaries identified for this thesis.

With regard to the prototype IQS, the Du Pont Electronics group (of which the test site is a member) had several existing computer systems which were used across all three sites in the group and were exclusively in English, so that, in this case, language was not considered to be an issue. However, in the specification of a generic system like the IQS, no such assumption can be made, and it is therefore suggested that further work in this area is required.

Chapter 8

Integrating User Requirements With Theoretical Necessity

8.1 Introduction

In chapter 6, a list of necessary functions for the IQS, drawn from quality theory, has been established. Subsequently, in chapter 7, the perceived needs of a user site have been considered. In the present chapter, the theoretically compulsory functions will be revisited in the light of user practice and preference in order to provide a more detailed functional specification.

8.2 Inspection Control and Results

Quality Control requires that production performance be judged on the basis of measurement of suitable criteria, usually of the product, but possibly of the process. This in turn requires that a list of criteria and acceptable values for each be laid down, along with definitions of the method of measurement to be used in each case.

Thus it is necessary for the IQS to provide mechanisms for:-

a) The holding and publication of specifications for quality control inspections which are to be carried out for every product and process. These specifications detail the criteria to be measured, the measurement method/equipment to be used, the acceptable limits of variation and the point in the production life cycle

when the inspection should be carried out.

b) The storage of inspection results in such a form that they may be available for analysis. For example, to determine process trends and intra-product variation. It should be noted that the analysis of past results may provide information useful for quality assurance activities to improve future products or processes, as well as for the improvement of current ones.

c) The control of updating of inspection specifications, so that only suitably authorised persons have access to make changes, and that, subsequent to an alteration being made to an inspection specification, it is assured that only the current version can be accessed for use, and that, where copies are issued on paper, a procedure is developed to ensure the recall of all obsolete issues.

8.3 Process and Product Monitoring

The core premise of Quality Control is the need to measure and compare findings with standards and specifications in order to monitor quality performance in production. This allows the clear identification of weaknesses and stimulates improvement activities. Thus a core function of the IQS must be the identification of suitable measures for each process and product. Hence, as stated above, it is necessary for the IQS to have access to all inspection specifications. It is also desirable that the IQS should control the updating and issue of such specifications to ensure that currency is maintained and that

all inspectors (human or machine) are working to the correct version of the specification. Further it is necessary to ensure that the measuring methods to be used can be relied upon, thus creating a requirement for equipment control, calibration monitoring, maintenance scheduling and staff control.

Hence it can be seen that the IQS should take responsibility for monitoring both the performance and reliability of processes and also, where appropriate, inspection of products at various points in the manufacturing cycle. However, monitoring those processes which directly contribute to the manufacturing activity is not sufficient to guarantee the quality of the product because the vast array of non-manufacturing processes which take place in an organisation also contribute to the quality of the finished product. For example, procurement, if the quality of raw materials or parts is poor, or delivery unreliable this will militate against the production of a good finished product, however capable the manufacturing processes are. Thus it is vital that procurement staff are aware of the impact of the items which they are responsible for purchasing on the product in which they are to be used. They must understand that purchase cost is not a good indicator of a "best buy"; but that whole life costs are more important. A more expensive part which is consistently good and causes no problems in the finished product may well work out considerably cheaper than a very low priced part which introduces a weakness into the finished product. Such life costs should take into account factors like damage to the company's reputation, as well as direct failure costs.

8.4 Decision Support and Problem Solving

The management of manufacture requires that information be provided to inform the decision making process. A clear picture to the true state of affairs must be available so that strengths and weaknesses can be pinpointed. This allows strengths to be knowingly exploited and areas of weaknesses to be investigated and improved. Thus the IQS must provide decision support through the provision of a set of standard configurable reports displaying the results of pre-defined queries against the historical records of inspection results. However, knowledge of inspection results alone does not give a sufficiently broad picture to enable the causes of failure or variation to be properly identified. It is therefore necessary to supplement inspection results with data from other sources, such as vendor rating, calibration, training and corrective action. It is important that this data can be properly related together so that links can be established. For example, if a customer complaint highlights a failure in a particular batch it should be possible to identify the equipment used in the production and inspection of that batch, to locate relevant maintenance and calibration records for that equipment, to identify which batches of incoming materials or goods were used in the batch, to identify which staff worked on the batch and demonstrate that they were correctly prepared by access to training or certification records.

In addition to the pre-defined reports and queries, an interface should be available for the definition of new queries and reports by users. This is necessary because of the great unpredictability of investigations which may need to be carried out. Also it is most undesirable that users should be restricted to a set pattern of investigation or

available queries and reports as this would severely handicap the solution of problems. After all, problems, by their very nature, are both variable and unpredictable, so that each problem investigation will be unique is some aspect.

8.5 Inter-System Links

In order to properly support the dynamic, investigative querying necessary for flexible problem solving and decision support it is necessary that the IQS have access to all data that may be considered quality relevant. However, as has been previously explained, much of this data is already held in other information systems in an organisation. Since it is undesirable to duplicate such data, it is necessary that inter-system links be established to permit access to the data by the IQS.

In a given organisation, the IQS may be required to access data from a wide variety of other systems. Since, in most cases these systems will be in existence long before the IQS, intervention to alter these systems to make them compatible with the IQS will be not only undesirable, but often impossible. They may be written by different software houses, in different languages and may even be running on different hardware. Thus it is incumbent on the IQS to establish and manage the requisite links. Clearly, since the IQS cannot require any changes to any external system, a great burden is placed on the IQS. Thus it can be seen that the establishment, maintenance and operation of inter-system links is the most complex function of the IQS and will require a very significant software development effort to implement. Furthermore, the inter-system links

necessary will vary greatly from one organisation to another, and may also vary over time. Hence, each IQS will have to be customised for the organisation in which it is to operate.

8.6 Generic Elements of a Complaint Monitoring System

The existence of a Complaints Monitoring System is an acknowledgement of the fact that only where a perfect system exists in a perfect world will there never, ever be a customer complaint. The quality aware company recognises the importance of having a mechanism ready for activation as soon as an indication of customer dissatisfaction is perceived, whatever the reason, whatever the root cause, and irrelevant of whose action gave rise to the dissatisfaction, whether it be internal to the company, in the sales or distribution operation, because of misleading advertising material, earlier in the supply chain, or even customer error. Such a company puts the customer first by adopting a "your problem is our problem" stance. It does not attempt to assign blame, but endeavours to find a means of restoring the customer's confidence as quickly as possible. This done, it looks to investigating the root cause and applying a modification to the system to ensure that the problem does not recur. Thus the Complaints Monitoring System must be both efficient and effective, furthermore, because it may only be used rarely, it must guide the user through an unfamiliar process, prompting necessary actions and requesting required data.

The function of a Complaint Monitoring system is to ensure that all complaints received

are actioned in such a way as to reduce, as far as possible, customer dissatisfaction; whilst also improving the production process to prevent re-occurrence of similar problems. Thus it is an important element in the process of TQM.

Certain data items are considered essential for a Complaint Monitoring system to properly fulfil its purpose, although most companies will choose to hold additional information to provide a smooth interface with existing company standards. These vital items are listed below:-

1. Customer Identification.
2. Date on which the complaint was received.
3. Details of the complaint.
4. Identification of faulty product.
5. Date on which a response was given to the customer.
6. Identification of the defect giving rise to the complaint.
7. Estimated cost of complaint.
8. Corrective action recommended.
9. Date on which corrective action was implemented.

The Complaint Monitoring system must provide a number of functions. It must provide a systematic method for documenting all details of a complaint and tracking the progress of that complaint, from receipt to implementation of corrective action (via the Corrective Action Procedure detailed below). A variety of reports can be produced to

highlight outstanding complaints, summarise types of defects reported, summarise complaints by product, or list complaints by value.

Furthermore, statistical analysis can be used to investigate relationships between types of defect, product or process. Estimated costs of complaints received may be used both as an indicator of company quality levels, and as a means of justifying expenditure on such things as new machinery, additional preventative maintenance or staff training.

Customer complaints frequently arise as a result of failures in the company's business system, not only because of poor quality goods. Such failures (for example, invoice errors or late delivery) are just as damaging to the company as the more traditional quality problems evidenced by faulty products, however they tend to be overlooked because they do not usually result in goods being returned, nor do they require additional production to correct. A Complaint Monitoring system provides the means of highlighting customer dissatisfaction caused by systems failures, although the adoption of TQM requires that all parts of the system will be continually monitored with a view to identifying and correcting weaknesses before they affect the customer.

Most importantly, the Complaint Monitoring system provides the means of ensuring that a dissatisfied customer receives a prompt response, and that the recommended corrective action has been carried out so that product and process quality may be improved as a result of the complaint.

8.7 The Corrective Action Procedure (CAP)

A Corrective Action Procedure is a requirement of ISO 9001/BS 5750, it is therefore a necessary part of the IQS. It has two roles; firstly in response to known failures, and secondly in improving the robustness of product or process where a possible weakness is perceived. It is clear that the Corrective Action procedure detailed herein may be viewed as a sub-function of Complaint Monitoring, although this is not its only area of usefulness because it will not only be called into action by a complaint, but may also be initiated as a quality improvement activity.

Within Du Pont, the following rules were defined. CAPs may be initiated as a result of an internally detected problem or from a customer complaint. On occasion, a CAP can be raised against a vendor whose goods or services are causing problems. In order to demonstrate how the CAP system might be used some typical scenarios are given below:-

a) An internal process, previously proven to be capable produces some non-conforming products which cannot be re-worked. The Production department raise a CAP to query the Quality Assurance, Marketing and Engineering departments to determine whether the product is OK to ship to the customer. The CAP gives rise to an instruction on what to do with the product, and a request to the Production department to provide detailed information concerning the cause of the non-conformity, along with a proposed method of curing the problem.

b) Some products have been made by an internal process, but the process is found to be incapable and is halted. The Production department raise a CAP as above. This CAP also seeks permission to continue running the process for some stated time period or production quantity so as to satisfy an identified customer order. If consent is given by the Quality, Marketing and Engineering departments, the run is continued with revised control limits, possibly combined with extra inspection or some other additional activity, the exact terms being stated on the CAP. Consent is only given where the process is judged to be able to produce products acceptable to the customer.

This situation may arise while equipment spares are on order, while further investigation of the problem is undertaken, or while the feasibility of a proposed improvement is checked and/or implemented.

c) All externally purchased goods and services must be supplied only by approved vendors. An exception may be made to allow purchase from a non-approved vendor by means of a CAP which recommends incoming goods inspection, combined with commencement of the vendor assessment procedure, which may then lead to retrospective vendor approval.

8.8 Supplier Records

Knowledge about the relationship between an organisation and its suppliers is a vital

part of the information required in TQM. Not only in terms of achievement of delivery schedules and supply of good quality goods, but also in the assurance of an adequate quality system being in operation in the supplier company. These records are also of significance in the light of Product Liability legislation.

In order to maintain and improve quality, it is necessary for an organisation to have knowledge of the quality history of all supplies which are purchased from external sources, just as there must be information transfer both upstream and downstream in the internal manufacturing process. It is not sufficient merely to measure the quality of incoming goods; their entire quality history must be available, especially if they are the result of a sequence of processes being applied by several companies, each adding value to the output of another, until raw material is transformed into finished product.

Furthermore, there is a need to ensure that communication of orders to suppliers is completely clear and unambiguous, and that there is verification that the delivered goods correctly match the order which they purport to satisfy. The first part of this problem must be addressed internally by design and production departments setting out their requirements formally so that Purchasing know exactly what is needed from the supplier. It must be clearly understood that competitive tendering judged only on grounds of price, is very detrimental to quality; suppliers bids must be judged primarily on quality, that is to say on how well they meet the specification laid down for the required goods or services. Where a bid is received from a company which has not previously been a supplier, it may be necessary to carry out an audit of that company's

quality system, so as to be assured that they can achieve the required quality. Only in a situation where all other factors are equal should cost be the deciding factor in the placement of an order.

Once an order has been received, it is necessary to ascertain if it meets the requirements laid down in the specification. Traditionally, this has been done by inspecting the goods on receipt; however, a wide range of evidence can be supplied with the goods if the supplier has a good quality system (particularly where SPC is in use) which can be used in place of incoming goods inspection. It is proposed that with the introduction of the IQS throughout the supply chain, this data could be obtain by establishing links between organisations on a wide area network. In addition, specifications for orders could be transferred in the same way.

Since on time delivery may be considered to be a facet of quality, it is necessary that the delivery performance of suppliers be monitored, both so that the reliability of the delivery promises made can be judged, and that the resultant effect on the purchasing organisation can be seen.

8.9 Training Records

Section 18 of BS 5750 part 0, section 0.2 discusses the personnel issues related to maintaining an effective quality system; these being training, qualification and motivation. The last of these three, motivation, can only be achieved by good

management and effective communication of the quality ethos to all staff. Training and qualification however must be supported by adequate information and formal monitoring and review procedures. Therefore, the IQS should include a module devoted to the support of these personnel activities.

A further issue was identified when employees of a large aero-engine manufacturing company described the operation of the company's staff training monitoring system to the author. On the surface, the system satisfied the requirement for regular review of the training needs of staff by annual discussions with supervisors, resulting in the definition of an individual training plan for the coming year. In practice however, the staff reported that the annual review was also used to determine the progress of staff through the pay and grading structure. The staff had no complaint about this use of the annual review, but were most unhappy about a basic weakness in the training monitoring system, which, they claimed, often resulted in negative feedback at the review. The problem concerned the recording of reasons for failure to complete the previous year's training plan; staff were often blamed for this despite the fact that, in many cases, courses had not been taken because of factors beyond their control. Examples which were given include increased departmental work-load which prevented their release from their job to attend a course; courses being cancelled either by the company or the training organisation; delegation of additional tasks by their supervisors, who instructed that the new tasks must take priority over training courses. At the annual review however, no account was taken of reasons for failure to complete the planned training courses, only the fact of failure was recorded and was taken to be

an indicator of lack of commitment on the part of the employee.

Thus, it can be seen that, while there is a clear need for a system to monitor and control staff training, it is vital that reasons for failure to complete a prescribed training programme are also recorded. This will allow analysis of problems which are demonstrably reducing the effectiveness of the planned diet of training activities. Hence, action can be correctly focused to remove these problems, rather than unfairly placing the blame for non-achievement of the assigned training goals on the employee. To complement such actions, it would be advantageous for training plans to be reviewed more frequently than the typical yearly cycle allows, so that, where someone is falling behind the proposed schedule for some reason, corrective action may be more timely. It is important that staff see the training programme, not only as a means of making them more effective workers, but also that it will lead to improved individual competitiveness in the job market as their working life progresses. Training records showing failure to complete a required set of training courses must never be used impede the progress of an employee through a merit related pay scale in cases where the cause of failure was outside that employee's control. If this rule is not applied, staff will be encouraged to oppose programmed training, because they will start to believe that training plans are being made deliberately unachievable so as to restrict their chances of qualifying for pay increases. Quite clearly, the development of such an attitude will severely impede any programme of staff development, and will, in the long term, lead to a degradation in both staff skill levels, and ultimately, to poorer product quality.

8.10 Equipment Calibration Monitoring

The basis for the design of this module is BS 5781: Measurement and Calibration Systems. Control of measuring equipment is a necessary part of the IQS because an accurate picture of quality performance in any activity can only be gained by measuring significant factors of the produce or process concerned. However, if such a picture is built from data produced by inaccurate, inappropriate or wrongly used measuring devices, it will be meaningless, or more dangerously, it might be assumed to be correct and acted upon. It is therefore necessary to institute procedures to control and monitor measuring devices, so that they are tested and calibrated at the required intervals and only by properly certified calibrators; and so that control may be exercised to ensure proper training and correct usage at all times. It is also necessary to recognise that certain types of equipment may be subject to the influence of environmental factors such as temperature, humidity or vibration, and that these factors must be monitored so that their effects may be gauged.

8.11 Traceability

The issue of traceability is an important one where the product being manufactured is safety critical (for example, in aircraft manufacture). In such cases, it is often necessary for a full history to be maintained for each item produced; this history being able to provide complete information about the production and source of every component or raw material of which the final part is composed. This allows for backward tracing to identify all source batches where a nonconformity is found later in the production cycle,

or even as a result of failure during use. Once the source of the problem is identified, it is possible to trace forward from the problem point to identify all other items which are likely to exhibit the same nonconformance, so that corrective action can be taken to preclude possible, maybe catastrophic failure in the field.

However, in the majority of manufacturing processes such detailed traceability is not required. For this reason, along with the vast extent and complexity of the information system needed to implement full traceability, this matter has not been addressed in this research programme, although the design proposed herein does not preclude the later addition of data structures and programs necessary to implement full traceability.

8.12 Product Liability

The ability to prove a defence against a charge of Product Liability is likely to become a financially significant issue as European consumers start to take advantage of the new Consumer Protection legislation presently being enacted across the European Community. The shift from the previous position, where the injured party had to prove negligence by the supplier or manufacturer, to one where the injured party now only has to prove that a fault in the product caused the damage. Thus, in terms of liability to the injured party, a claim can no longer be dismissed for lack of evidence of negligence, but must be allowed where a fault can be demonstrated. Hence, it is important that responsibility for that fault can be correctly attributed to the point in the manufacturing process or supply chain where it was introduced. This has two purposes;

firstly, that the financial burden of any resulting damages is appropriately assigned, and secondly, that corrective actions can be implemented to prevent a similar failure in the future (note that this may include product recall in the case of a serious fault).

The IQS proposed herein will certainly contribute to the ability to identify quickly the point of failure by providing evidence of correctness at key points in the process through the quality history records. Once the point of failure has been identified the IQS may also be used to investigate possible reasons for the introduction of the fault. This may include the identification of weaknesses in the quality system itself. However, as presently specified, the IQS cannot provide a complete and comprehensive solution to the problem of proving a defence in a Product Liability prosecution because only an IQS incorporating full traceability will allow the unerring detection of every reason for failure and the identification of other affected products.

Chapter 9

Technical Issues

9.1 Introduction

The preceding chapters have examined the determination of a functional specification for the IQS. The present chapter seeks to identify the constraints which may have a bearing on the practical implementation of the IQS, both in generic terms and for a particular organisation, and examines the technical issues which were taken into account in the design and implementation of the system.

9.2 System Prototyping

A prototype system was constructed to investigate the practicality of the proposed system. The prototype also served a secondary purpose by demonstrating clearly and unambiguously what was being proposed in order to elicit comments and criticism from potential users. Furthermore, it was relatively easy to incorporate user suggestions into the prototype. This provided several advantages; firstly, the appropriateness of the suggestions could be tested, both by the system designer and by users; secondly, users had the satisfaction of seeing their ideas put into practice, a positive effect even when the idea was later found not to work as anticipated; thirdly, increased user "buy-in"; and fourthly, the swift evolution of a system that users were happy to work with. In the following sections, the role of prototyping in the development of a system such as this will be considered in more depth.

9.2.1 Physical Versus Software Prototyping

In the world of engineering design, a prototype is a mock-up built to ensure that a new design is correct. It may reveal flaws in the design which were not evident in the drawings. Such flaws may be in any of the following areas:-

1. practicality of manufacture.
2. suitability for the intended purpose.
3. safety.
4. reliability.
5. cost.

In order to investigate design correctness, it is not always necessary to build a full scale replica of the proposed item (for example, in the construction industry or ship building), as valuable information can be gleaned from a model. In these circumstances, a model does not necessarily have to be an exact replica of the real item, either in the component used, the functionality provided, or the materials of which it is made as those proposed for the actual article. Only that degree of similarity that is sufficient to demonstrate the features envisaged by the designer (and sometimes also the customer) is required, even the size of the model may be varied from that of the actual item according to the purpose of the model; thus a life size, non-functional mock-up may be used to test the fit of a product which will form part of a larger assembly, while a functionally accurate scale model (usually, but not always, smaller that life), may be used to test the functional correctness of the design. Such prototypes are built solely for

testing purposes and are normally written off after use, they therefore impose an overhead on the design process. An additional overhead is introduced by the need to design and build (or purchase) testing equipment with which to assess the prototype. Indeed much effort may be required to determine the most worthwhile and reliable methods of testing and to interpret correctly the meaning or implications of the results.

A software prototype also serves this purpose. However, it provides much more input to the design process than physical prototypes can, by virtue of its more malleable nature. A software prototype may serve many purposes; it may be used as an analysis and design tool, as a means of refining the system specification provided by the client, for demonstrating the feasibility of a proposed system, and as a training aid prior to the introduction of the full operational system. Furthermore, software prototypes are not confined to only modelling computer programmes, for with the increasing use of CAD and CAM, physical products may now also be modelled and, to a greater or lesser degree, tested in software. For example, it is now common practice to carry out stress analysis on complex structures by the use of computer models, and work is being done under the auspices of the ESPRIT programme to develop and evaluate fatigue testing software models for cars. Although the formulation and proving of such models is expensive, considerable advantage may accrue because of the facility for easy adjustment of a wide range of model parameters provided by a software model.

Software prototyping is very valuable as a means of helping users to provide a sufficiently detailed and accurate specification to allow the development of a new

system which truly reflects their requirements. The provision of this type of specification is something that most users find quite difficult because of a lack of familiarity with the capabilities and weaknesses of computerised systems; but also because of a failure to recognise that the analysts and programmers involved are neither telepathic nor, usually, intimately familiar with the details of the task which is to be performed by the new system.

The availability of powerful software tools, such as fourth generation languages, have significantly reduced the time needed to develop and modify software prototypes. Thus a major feature of the modern software design process is an iterative cycle of prototype building and testing, coupled with evaluation by the client and subsequently by discussion of suggested changes and improved functionality, leading to a revised specification for the next version of the prototype.

The iterative prototyping cycle addresses the problem of transforming a client's vision of a proposed system into a formal specification which clearly defines the functionality required, the data sources and sinks, the user interfaces, and the interactions between system elements and with external systems. These points are often not clearly perceived by the client, who has a tendency to see the system only in terms of the results it will produce. Thus for example, a system is to maintain certain records and produce reports; no indication is given of where the data will come from, what procedures will be employed for collecting, updating and entering that data, and, apart from vague mentions of report structure, without stating how report generation is to be initiated or

what parameters are to be used to control report content. These questions can be brought to the attention of the client during the prototyping cycle, which can also be used to verify the correctness of the client's perception of the system.

Another difficulty which often arises is that a person who is very familiar with a situation or procedure tends to assume that certain elements "go without saying" because they are so obvious that "everyone knows that!". Such things are therefore often omitted from descriptions of the activity, and, when the listener is not similarly familiar with the situation, the omission may go unnoticed until such time as the original user is presented with a new system which does not include these "obvious" elements.

Hence this technique brings with it the benefits of increased client satisfaction combined with a strong feeling of ownership and a commitment to the software, coupled with faster, more accurate system design and development. Additionally, a software prototype need not be thrown away after use, it can often be used to form the core of the finished system, thus reducing the overall cost of the design phase of the project, and shortening the time taken to implement the new system.

9.2.2 Prototyping as an interface between the analyst and the non-computerate user

In many systems analysis situations, the analyst must communicate with those who have little or no knowledge of computers. This may require considerable sensitivity on the

part of the analyst as this circumstance may create a number of problems which must be overcome:

a) Fear of computers, particularly the fear that the computer will infringe on the status, skills or occupation of the human, thus making him obsolete and eroding his self-image. This fear results in opposition to computerisation.

b) Lack of understanding of the capabilities (and deficiencies) of computers and how these might usefully be applied to the task in hand.

c) Fear of "breaking" the computer system. People who have had no previous contact with computers are often afraid to touch them because they think that computers are expensive and imagine them to be fragile, they fear that they will be accused of damaging the computer if they do something wrong.

d) Fear of losing data. Many people who have little or no experience of computer use have a profound fear that their actions may cause the erasure and therefore loss of important data. As a result, they are very loath to entrust their data to a computer system, especially in view of the effort which may be required for the initial data entry. This fear is also common to those with considerable experience, the difference being that they know what steps should be taken to safeguard their data (ie. frequent, regular backups, kept in secure locations). Experienced users are, because of their greater knowledge, less likely to make

the type of catastrophic mistake as novices, however, this greater knowledge may be dangerous as it often allows the experienced users to circumvent safeguards which would protect the less experienced.

It is therefore necessary for the analyst to educate those involved in such a way as to remove the fear and provide an insight into the possible benefits of interaction with computers. However, it is important that this education process is implemented in a sensitive manner, so that those involved do not feel pressurised in any way.

An effective way of achieving this goal is to provide a computerised tool to carry out some task with which the person is involved. It does not matter if this tool is only a little more than a sketch of the process, the important thing is to set the proposed user at ease, and then provide a small taste of how computerisation could help him. The use of a very simplistic tool at this stage reduces the user's conception of the computer as a threat to his position by giving a feeling of superiority ("It isn't as flexible as I am" or "I wouldn't do it that way, such and such a method is better"). The user can see ways of improving the tool to make it perform better and usually cannot resist the temptation to make suggestions. In this sort of situation many users become emotionally involved with the tool; it becomes their "baby". Once this change in relationship between the user and the computer has been achieved, the fear and feeling of being threatened by the machine are largely removed.

Interaction with a simple piece of software can also be used as a means of giving the

user confidence in the robustness of computers. This is vital if a user is to feel comfortable and relaxed about the prospect of regular computer usage in the course of his job. A user who is frightened will also be on the defensive, and will therefore tend to be uncooperative when approached about the introduction of a computer system.

Finally, the user gains experience in the process of developing a customised computer program. He learns about the sort of questions the analyst will ask and the level of detail he will be expected to give in his responses. This development of the user's understanding of his role in the design process is valuable both in building the user's self-confidence, and in improving the quality of the interaction between user and analyst, thus leading to an improvement in the quality of the finished system. The more familiar a user is with the software design process, the more likelihood there is that the analyst will obtain reliable and compete information, which will lead to the production of a "right first time" solution. Thus saving time and money which would otherwise have been spent on fixing problems introduced into the system by poor communications between analyst and user.

9.3 Analysis of data volumes for Du Pont Electronics, Bristol

In order to roughly estimate the magnitude of data storage required to support the IQS, analysis of the production profile at the test site was undertaken. This analysis did not attempt to cover more than the requirements for provision of inspection specifications and storage of inspection results, although the likely needs of other functional parts of

the IQS are also discussed. In addition, some similar information was obtained for other types of product at other companies. Although this does not provide such a detailed picture, it does give some guidance as to the variations in data storage needs from product to product.

This site is considered to be small both in relation to other electronics manufacturers and to manufacturing sites in general. Furthermore, the product manufactured at the site is quite simple, having few process steps. The site cannot therefore be considered to be typical in terms of data volumes, but can provide a good estimate of the minimum size of many of the modules proposed for the IQS.

Given the following production figures, which are for December 1989, it is possible to estimate the data storage requirements for one month, and from this to extrapolate overall storage needs for the quality system.

9.3.1 Inspection Specifications and Results

1431 batches were made during the month of December 1989 with the site operating on a 24 hour basis. The average batch size was 400 items, with the range of batch sizes being from 1 to 500,000 items, although the majority of batches fell into the range 100 to 1000 items.

For 90% of the total production of the site, inspections are carried out at the start and

end of each batch, and then at intervals of about 200 items during a batch (roughly every 30 minutes). Typically 5 items are inspected on each occasion. Inspection is spread across several significant points during the production cycle with typically a total of 20 characteristics are inspected, with up to 3 additional inspections being required for some of the more complex product lines. Thus for an average batch of 400, a total of 300 items in the form of inspection results will be collected (assuming inspections at start of batch and end of batch, with one patrol inspection being carried out during the batch run).

The remaining 10% of the site's production is special, non-standard products. These items undergo 100% inspection. Thus, for a batch of 400, a total of 8,000 items of inspection result data will be collected.

The product range comprises approximately 700 products, which fall into some 130 families of similar products. Since normally a single inspection specification is used for all products in a given family, it is therefore necessary for the database to hold at least 130 separate inspection plans to support this product range, although there may be a need to hold additional plans to allow for a variety of alternate production processes which may be used for a given product, or where a customer requests some form of extra inspection. The Inspection Plan specifies all inspection activities to be carried out during the production cycle of a particular product.

The Works Order Number identifies the batch. It is sourced from the Production

Planning system, MAS-H and supplied to inspection stations by the CQDB. It should be noted that, at present, works orders for finished parts contain a bill of materials showing which semi-finished parts must be produced and giving an internal works order number for this purpose, each of these internal orders may be treated as an independent entity, where each works order uniquely identifies a part in production.

The Inspection Plan specifies what inspection events are to be carried out during the production cycle of a given product. Inspection events are scheduled to occur after stated process steps during the production of goods for a works order, so that for a given product there may be several inspection plans which may be used according to the type of production process specified in the production schedule and hence the most appropriate inspection station to be employed. These may be either a standard inspection procedure for the part, or may be supplemented by some additional inspection specified by the customer. The specification of each inspection event contains the following information:-

a) Inspection plan identification code.

b) Type of inspection station to be used (ie. CAI, automatic or manual).

c) When in production cycle inspection is to be done (ie. process identification code).

d) Details of inspection specification to be used.

The CQDB will determine from the production schedule which inspection details must

be sent to which inspection stations. It is possible that a single station may receive more than one set of instructions for a single works order, although at the Bristol Du Pont site, this is extremely unlikely to happen. It is also possible for more than one inspection station to be used to carry out the same inspection, although this is also unlikely.

For each characteristic to be inspected the following details are needed:-

Characteristic name OR Inspection instruction (50 characters)

Sample rate OR Sample size (integer number)

Number of measurements to be taken (integer number)

Inspection configuration OR Type of inspection method (2 characters)

Nominal value for characteristic (real number)

Maximum acceptable value (real number)

Minimum acceptable value (real number)

9.3.2 Complaints

At the Du Pont site being studied the rate of receipt of customer complaints was about 2 per month, meaning that 0.2% of orders were generating customer complaints. 90% of these complaints were resolved in 2 to 3 days, with a further 5% being finalised within 1 month and the remaining 5% requiring up to 6 months work. A "standard" complaint record is composed of 22 data items, one of which is a free-form problem

description field. Linked to the formal complaint record there may be a number of reports documenting the investigation and any action taken to implement a solution. Normally, each complaint will cause a CAP request to be raised.

9.3.3 Corrective Action Requests

Since the Corrective Action Procedure (CAP) was never fully operational, it is not known how heavily it would have been used. However, it is reported that when a CAP system was introduced at another site in the Du Pont Electronics group over 1000 requests were received in the first week of operation, although the request rate settled down to about 1 per week after the system had been running for 12 months. At that time there were about 100 active CAPs with this number gradually dropping to about 70 as the steady state was achieved.

The CAP will generate quite large quantities of data because must of the relevant and necessary information is descriptive in nature. Although some codification will be possible, and in fact, must occur to allow linking of related CAP's, it is vital that all investigation reports and correction ideas be maintained in full so that information is not lost because of incorrect or over-reductive codification. It is particularly important to realise that the perceived significance of a given piece of information may vary considerably during the life of an individual CAP, especially where that CAP prove difficult to solve.

9.3.4 Equipment Calibration

The site used some 67 items of equipment which required regular calibration. The calibration intervals being typically 6 months (54 items) or 1 year (13 items). 1 official calibration agency was used and 3 staff were qualified to undertake certain calibration tasks. These staff were not required to undergo regular re-training or re-certification for these activities. Those items of equipment requiring calibration monitoring were described by 14 data items, and certified calibrators by 6 items.

9.3.5 Training Records

Of the 120 persons employed on the site (either as permanent or contract staff), it was necessary to maintain historical information about qualifications and previous training for some 50%. Training plans were held and monitored for 60 staff, and a further 30-40 undertook work which required special certification, which in some cases had to be renewed at regular intervals or supported by, for example, eye tests in order to maintain their currency. In addition, records of 5 approved trainers and 46 individual training courses were held. For each training activity required by a staff member, 7 data items are held, and for every approved course there are also 7 items, additionally, 5 pieces of information are held for each approved training organisation. These records were maintained on a spreadsheet.

9.3.6 Vendor Records

The site was supported by a fairly small supplier base, the principal supplier being other parts of the Du Pont organisation. Where items were Du Pont sourced, no incoming goods inspection was carried out.

Bought in products may be classified into one of four categories:

a) Product "raw material" which included plastics (3 suppliers), wire (5 suppliers) and semi-finished connector assemblies (4 suppliers). Fairly large deliveries of these items came in about once a week, with the site moving towards JIT but still holding stocks sufficient for 2 to 3 weeks production. Incoming goods inspection ranged from none for plastics (largely because the site did not have the equipment necessary to undertake the inspections required for plastics), to very comprehensive for wire.

b) Production equipment which included machinery and equipment (3 suppliers), computers (1 supplier) and jigs and tooling (8 suppliers).

c) Personnel (2 staff agencies). This was important because of the high levels of contract staff employed on the site.

d) Office goods (2 suppliers) with deliveries being made two or three times each week.

9.4 Hewlett Packard Systems

As has been mentioned previously, the Du Pont Electronics site under consideration was a small one manufacturing a limited range of fairly simple, low value products. Hence, it is of interest to consider, in passing, data volumes encountered for a more complex, high value product. Both of the systems described were custom built by Hewlett Packard for their own use, with the former having been later commercialised.

The first was developed at the Hewlett Packard Disc Memory Division (DMD) in Boise, Idaho, USA, in the early 1980's and is described in Hewlett Packard [53]. DMD had established the need for Statistical Process Monitoring of the disc media module manufacturing process, but it was far too complex for manual data collection and analysis. Thus "HP Quality Decision Management/1000" was developed. DMD produced of the order of 1750 disc memory media modules per month. For each media module over 400 items of data had to be collected for analysis during a complex manufacturing process with many process steps.
Thus in excess of 700,000 data items were collected per month.

The second, developed by Stiles [123] in 1989 for use at the Computer Peripherals Bristol division of Hewlett Packard, is concerned with Production line data collection and unit tracking. It was introduced to cope with a variety of similar products being built on a single production line, and was required to ensure that each variant passed through the correct processing steps and underwent the appropriate tests. It is clear from Stiles' report that the remit of his system is considerably restricted compared to

that of the generic IQS described herein, however, it is highly likely that a module with this type of functionality will be a core element of the IQS. The maximum capacity of the production line for which Stiles' system was developed was 12 units per hour, with typically 5 processes being carried out on each unit and some 8K bytes of data being collected per unit. Thus 96K bytes of data were gathered per hour.

No mention is made of the length of time that the data is retained by either system, however, it is reasonable to suppose that, particularly in the first system, analysis of process behaviour over a period of several months might be desirable to track the effects of improvement activities which have been undertaken, for example, changes of vendor or process modification.

9.5 Choice of a Software Tool

After examination of the characteristics of each of the database models (summarised in appendix 2), it was decided that the flexibility provided by the Relational model was most appropriate for the development of a prototype central quality database to act as the kernel of the IQS. Furthermore, that it would provide growth potential as the scope of the IQS developed in actual use. It was then necessary to identify a commercial database management package for use in the prototyping process. The following criteria were considered to be important and were used to pinpoint products for further study.

9.5.1. Portability

Software portability was considered to be vital in a system of this kind because any organisation considering implementing such a system should have leeway to decide which manufacturer's computer hardware is most appropriate to their circumstances. Thus a company should have the option of extending its existing computing facility, rather than being forced to purchase a special new machine. The implications of this flexibility go beyond the initial cost of computer kit, as it is important to recognise the overheads inherent in introducing additional, different hardware and software. This type of diversification may place a great burden on the computer operations and support section within the company, thus necessitating the employment of additional personnel and the provision of an expanded training programme or alternatively the reduction of support or services in other areas. Additional problems may be caused where there is a need for the new database to communicate with existing software which may be implemented on different hardware.

To ensure portability in the finished system, the database management software should be available on a wide range of computer hardware. To this end, only products which ran under the UNIX operating system were deemed eligible for consideration, although many of these will also run under other operating systems (for example, Primos, VMS, MS-Dos). MS-Dos was not considered for use as the base operating system because it is not be able to provide the multi-user access necessary for the CQDB. However, MS-Dos was used as the operating system for the QDAAS in the IQS since it was able to support the necessary data exchange with the central computer.

As a consequence of the need to allow a wide selection of hardware to act as host machine for the central database, means of ensuring that the software could be quickly, easily and reliably ported to the chosen machine had to be considered. Although many commercial software products are available to run on a variety of machines, differences in the operating systems frequently cause problems in transferring programs and data between machines. A major reason for this is that most operating systems are proprietary to particular manufacturers. There are, however, two operating systems of which this is not true; UNIX and PICK. Both of these were developed independently of hardware manufacturers, and have since been ported onto many different computers. UNIX was selected because it is very much more widely available, also because PICK is typically used for a selection of quite specialist applications, rather than as a general support environment, and would therefore be considerably less likely to be already in use as a platform for general manufacturing software (eg. Production Planning).

9.5.2. Program Development Environment

A comprehensive program development environment should be provided to allow easy prototyping, and to facilitate future modifications to the system. There should also be a consistent, well-structured interactive query interface. Many modern DBMSs are supplied accompanied by comprehensive system development environments comprising a number of 4GL tools. This move away from the use of languages such as Cobol for database manipulation has many benefits:-

a) Significantly reduced development times for both entirely new databases and for additional applications running against existing databases.

b) The ability to produce prototypes rapidly. this allows better communication between client user and software developer and thus results in finished systems which provide significantly enhanced levels of user satisfaction when compared with software developed without prototyping.

c) The ease of use and simplicity of many DBMS related 4GL tools allows users to easily define reports and queries, and even quite major application extensions for themselves, without the need for specialist programmer support. This greatly enhances the usefulness of the data by enabling the answering of unforeseen, one-off queries and the production of special extra reports. This is particularly valuable where the database is being used to support problem investigation.

d) In addition to reduced development times, 4GL code tends to be significantly shorter and easier to test than traditional 3GL code. This means that it is also much easier to maintain. As a result, software life cycle costs are greatly reduced.

According to Bate and Vadhia [6], the most common 4GL tools provided in association with DBMSs include the following functionality:-

a) Data entry form generators which include facilities for defining data validation rules.

b) Query generators which help to protect the user from the vagaries of SQL by providing easy to use methods of defining queries, for example, using the Query-By-Example method.

c) Tools for defining and altering the structure of database tables and fields.

d) Tools for designing and generating reports.

e) Data transfer mechanisms to support the exchange of data between the database and external systems such as spreadsheets and word processors. In some cases, this facility is automatic for a stated set of software, while in other systems fuller flexibility is provided by the use of special database manipulation code embedded in 3GL programs in languages such as C or Pascal, which are then compiled via special pre-processors.

f) System generators for building and controlling menu-driven user interfaces for applications.

g) Provision for graphical output of the results of queries. This may be very helpful for users as graphical display can greatly assist the appreciation of trends

or variations in data which would be much more difficult to detect and assess when the data is presented in tabular form.

9.5.3. Support and Vendor Commitment

The software vendor should have a proven commitment to the continued support and maintenance of the product, this should be evidenced by the existence of an established user-base and an active user group. This is an important consideration because the costs of changing to a new software product can be very high if major systems have to be re-written. Furthermore, only companies with a large, experienced programming section could hope to support a major software project dependent on a commercial product which was no longer maintained by its vendor. A serious bug in the product could render a system unusable, were it not possible to obtain a fix, or a work-round for the problem. It is possible that maintenance of the product might be taken over by some third party (for example, a major user with a strong programming section), but this is rare.

9.5.4 Selection Method

Selection was achieved by drawing up a list of some 34 important technical items. Details of these items was obtained by studying technical documentation on product functionality and performance, perusing the computing press for comments on product reliability, performance, ease of use and quality of support, and viewing demonstrations

of the product. This list, which could be roughly divided into two distinct types of criteria, these being technical capabilities and implementational details, included such questions as pertained to conformance to Codd's 12 Fidelity Rules for Relational Databases, along with details such as maximum record and file sizes, maximum number of sort keys and indexes, maximum number of tables which may be active to contribute data to a single view, availability of dynamic index creation and dropping, extent of distributed query capabilities. Finally, after analysis of the findings, a short list of possible satisfactory products was determined. These were assessed by gaining hands-on experience after obtaining evaluation copies of the short listed products.

Chapter 10

Design and Implementation of the Prototype IQS

10.1 Introduction

Taking into account the perceived requirements of the user site and combining them with the theoretical structure implicit in quality management theory, has resulted in the functional specification set out in the preceding chapters. When this was overlaid by the various technical issues (such as data volumes) presented in chapter 9, it became possible to propose an initial structure for a prototype IQS, and to suggest routes forward towards a full site-wide implementation.

The implementation was phased, with the development of the inspection control module being completed before work commenced on other modules. This was deemed necessary in order to satisfy the terms of the ACME grant under which the early part of the work was funded. On completion of the ACME project, the author continued the design and implementation of the prototype IQS on a part-time, unfunded basis. She continued to receive input from Du Pont staff on a voluntary basis and would particularly like to acknowledge the help of the former Quality Manager who willingly carried on supporting her work, even after he had been made redundant by the closure of the Yate site.

10.2 Physical System Structure - A First Approximation

In order to provide flexibility in the integrated quality system, it was decided that the system functions should be distributed between a central minicomputer and a number of microcomputers situated throughout the site.

This distribution is based upon the functional dichotomy evident in quality activities. Firstly, there are operations which are closely associated with the actual manufacture of products, wherein quality control and certification are the major activities. Secondly, quality management activities are focused upon study and improvement of all operations in the organisation with a view to overall quality improvement. This latter category includes product and process design activities which rely heavily on records of past experience, predefined product or process specifications or constraints, and legislative requirements and restrictions.

It is proposed that the minicomputer will house the central core of the IQS; the central quality database (CQDB). The CQDB will not only be the repository of all summary quality information, but will co-ordinate data exchange with other information systems (any or all of which may be resident on a physically separate computer), such as those concerned with production planning, scheduling and commercial activities, via a local area network (LAN). Also linked to this LAN would be a number of microcomputers (specifically conforming to the IBM-PC de-facto industry standard) which would provide direct process/product monitoring and support process control activities such as SPC.

These microcomputers would be largely autonomous in their operation, communicating with the central database system only to obtain inspection specifications and to return summaries of quality levels which had been measured. The operation of these local process monitoring units (sometimes called Quality Data Acquisition and Analysis Stations (QDAAS)) is described in Wort and Tannock [150], Tannock and Hill [132] and Wort and Tannock [151].

The loosely linked, distributed structure proposed for the prototype permits a company planning to implement such a system a high degree of flexibility, both in the choice of hardware to be used, and in the level of initial investment necessary to set up the system. This flexibility is enhanced by the use of the UNIX operating system as a platform for the CQDB, thus providing considerable latitude in the selection of the central minicomputer. A minimum system might consist only of a small minicomputer or workstation (costing of the order of £25,000 in 1989), linked to one or two microcomputers running MS-Dos (at about £2,000 each for an IBM-PC clone, also a 1989 price) plus the cost of installing the LAN. Expansion of the system can be carried out very gradually by adding extra microcomputers or increasing the capacity of the central minicomputer according to the changing needs of the organisation.

The diagram at Figure 10.1 shows a schematic of the initial prototype which would form the core of a typical distributed quality database. There are no limitations as to the number or type of local monitoring unit, provided that they are capable of communication on the local area network; and hence this approach may be used in

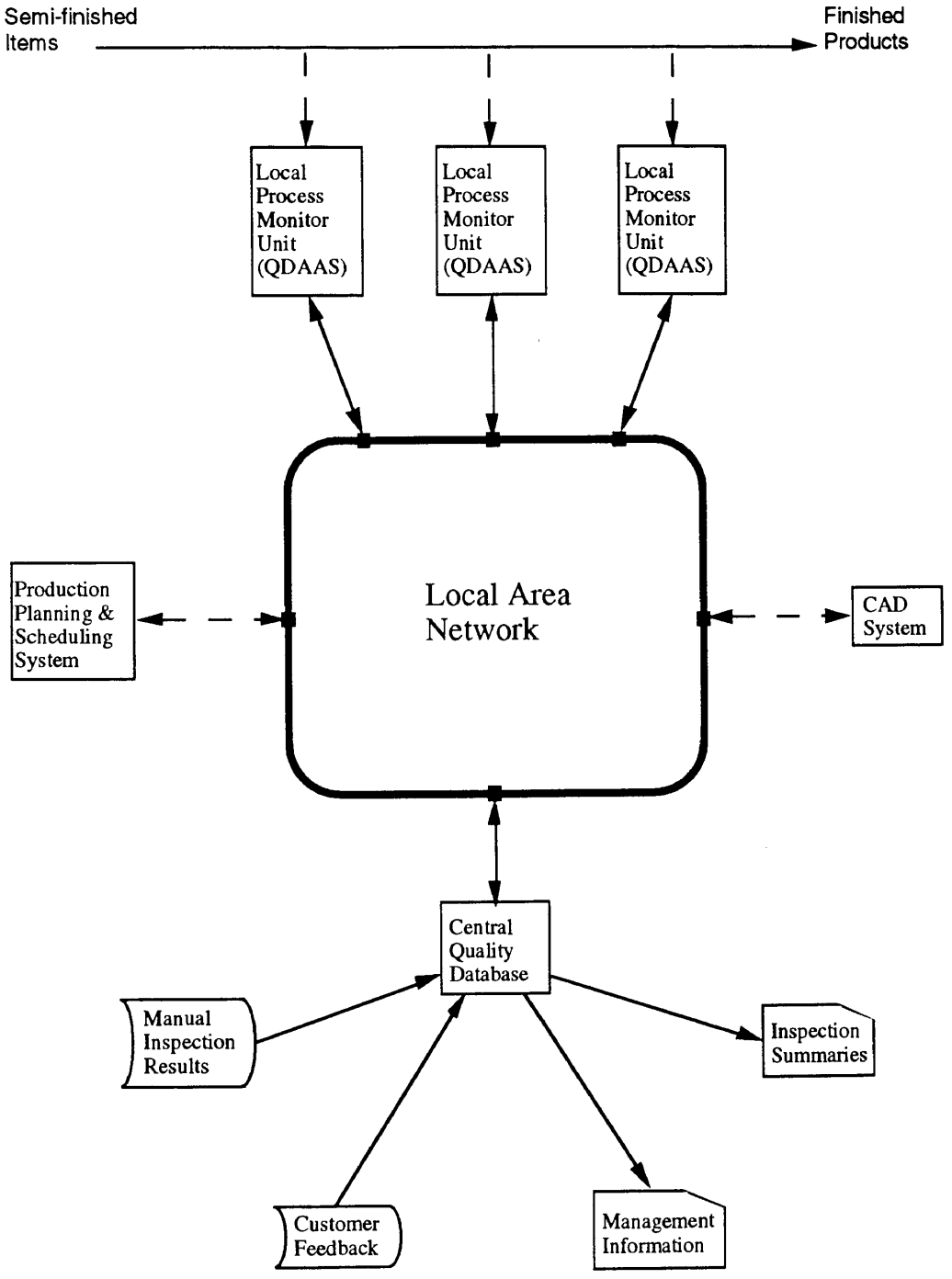


Figure 10.1: Schematic of the Initial Prototype

plants of any size. It should be noted however, that the use of the Ethernet LAN would impose some constraints on the physical distance between the most distant nodes. This is by no means an insurmountable difficulty; simply requiring additional equipment, rather than a modification to the networking strategy chosen for the prototype IQS.

The distributed nature of the integrated quality database requires a number of links with local monitoring units situated in various parts of the plant; for example, incoming goods inspection, production areas and the desks of quality function staff and management. Communications with other automated elements of the manufacturing system, such as production scheduling and design are also necessary. As a long-term goal, external links to suppliers, customers, other company sites and sub-contractors might be considered desirable, although clearly, access to the database from these external sources must be strictly controlled. Flexibility and the ability to expand the configuration in response to future need are essential.

A local area network (LAN) was adopted as the only possible solution to the problem of linking a number of otherwise independent computers situated in production and office areas so as to allow a distributed database application to operate. The prototype IQS uses an Ethernet LAN (which conforms to the IEEE 802.3 standard) combined with the Sun NFS file transfer protocol.

A variety of access modes must be provided for the CQDB. There is a clear requirement for direct manual data input to the database for certain specialist data entry

tasks. Manual data input was also seen as the most flexible method of entering rarely updated information, where the costs associated with setting up any more automated form of data entry could not be justified by the benefits gained. In most cases, the more frequently occurring data entry tasks will be carried out via the QDAAS which have facilities for automatic or semi-automatic data collection. These are described in Wort [149].

The prototype CQDB was built using a popular commercial Relational DBMS product which is available on a wide variety of hardware, running under several different operating systems. The selection of a suitable DBMS has been described in chapter 9 of this thesis, whilst arguments associated with the choice of database model are set out in appendix 2.

10.2.1 The Initial Prototype

The functionality of the initial prototype was very simple; it gathered inspection specifications from their source (typically the CAD system), from the production schedule, it caused the appropriate inspection specifications to be issued to the QDAAS, and finally, it collected inspection results from the QDAAS at the conclusion of a batch. As the prototype was developed, this functional element became known as the Inspection Control and Records module (ICRM).

In the prototype ICRM, inspection specifications were entered manually, although in

a full implementation this method would only be used in exceptional circumstances. The normal method of acquisition of inspection specifications would be direct data transfer in electronic form from the CAD system. This was not feasible in the prototype for two reasons; firstly, because of the low level of computerisation of the design function at the user site, and secondly, funds were not available to set up such a system in the laboratory.

The product range manufactured at the test site was composed of a set of fairly simple, low cost items. Although new product lines were under development, the bulk of the production effort was devoted to electrical connectors. Several families of related products were made; all based around the same basic concept; that of a plastic body holding a predefined number of metal pins in a particular configuration. The most important families were:-

a) single row, straight body (maximum of 72 pins)

b) double row, straight body (maximum of 72 pairs of pins)

In addition, products with bent pins (both internal to the body and external) were available in double and single row versions. Each family contained a wide range of variants, defined by the length of the body along with the number and position of pins (some customers required connectors with vacant pin holes in predefined positions). Thus a given product will be governed by the "family" specification modified to achieve the required variation. The company produced a catalogue of "standard" variants, but also manufactured customer specific variants. The specifications also defined the

inspection criteria for the product, but not necessarily the production method. These may be supplemented by additional inspections requested by a particular customer, and may apply to a single production batch or to all batches destined for that customer. Also special procedures may be applied to particular products, families or processes for a fixed time period during the course of a problem investigation or as a temporary "fix" for a known problem.

It is the role of the CQDB to obtain, and maintain in an up-to-date state all such specifications, with particular emphasis on those elements related to inspection. In response to the production schedule the CQDB must deliver to the appropriate inspection points the necessary specifications and instructions to guide the quality assessment of batches during manufacture. Thus although inspection activities across the site will be under the direction of the CQDB, it will not take part in actual inspection which will be delegated to the QDAAS. On the completion of a batch, the involved QDAAS report their findings back to the CQDB for incorporation in historical records. The complete inspection history of a given batch may not come from a single QDAAS, but is more likely to be an agglomeration of results from several QDAAS monitoring different characteristics at different stages of the manufacturing cycle, with the further possibility of a batch being split between two production machines at some point in the cycle, and batches of the same product undergoing different processes during production.

Arguably, the most significant operation in the manufacturing process was the insertion

of pins into the plastic body. At the time of this study three different processes were in use for this operation, with volume and complexity of pin configuration being the selection criteria. It was the most highly automated of these processes which was the focus of the work by Wort and Tannock [150] on high speed inspection using a vision system, and that of Tannock and Hill [132] on process monitoring by studying insertion force profiles. These activities required support from the CQDB so that they could be correctly configured at the start of each batch. Thus the CQDB had to provide the necessary inspection specifications and sample insertion force profiles to the PC controlling the vision system and force monitor. The PC then used the provided data to reconfigure the two monitoring devices. If a nonconforming product was detected the device reported this fact to the PC, which then initiated rejection of the product. In the prototype, real time statistical analysis of the data was not undertaken, but with such added functionality, the presence of unacceptable process variation could be detected by the PC and brought to the attention of the operator for investigation and correction.

The initial prototype could not really be said to conform to the definition of a quality system employed herein because it only provided functionality sufficient for Quality Control, with perhaps limited support for some aspects of Quality Assurance. Thus it was necessary to extend the prototype in such a way that it might approach full support of TQM.

10.2.2 The Extended Prototype

It is evident that there is a need for linkage between the ICRM and other modules, such as Equipment Calibration Monitoring and Training Records, so as to demonstrate that all inspection results collected are reliable, and have not been affected by the use of out of calibration measuring equipment or inadequately qualified staff. Hence, the extended prototype comprised a number of loosely linked functional modules, each designed to operate as free-standing, independent entities, but able to provide or request data from other modules as required. The modules defined in the extended prototype were Equipment Calibration Monitoring, Staff Training Records, Corrective Action, Customer Complaints and Vendor Monitoring. A schematic for the extended prototype is shown in Figure 10.2.

Together, these modules provide a good base for supporting management decisions and underpinning the investigative side of problem solving. They provide a broad range of standard reports which are given greater flexibility by the ability to specify parameters to adjust content and presentation. For several of these functions, such as the monitoring of staff training or equipment calibration, a menu-driven user interface was developed. This modular structure provides easy user access both to specially designed data entry and validation functions, and to the sets of predefined reports, along with facilities for ad-hoc querying of the data and the definition of new reports which may then be linked into the system for future use if required.

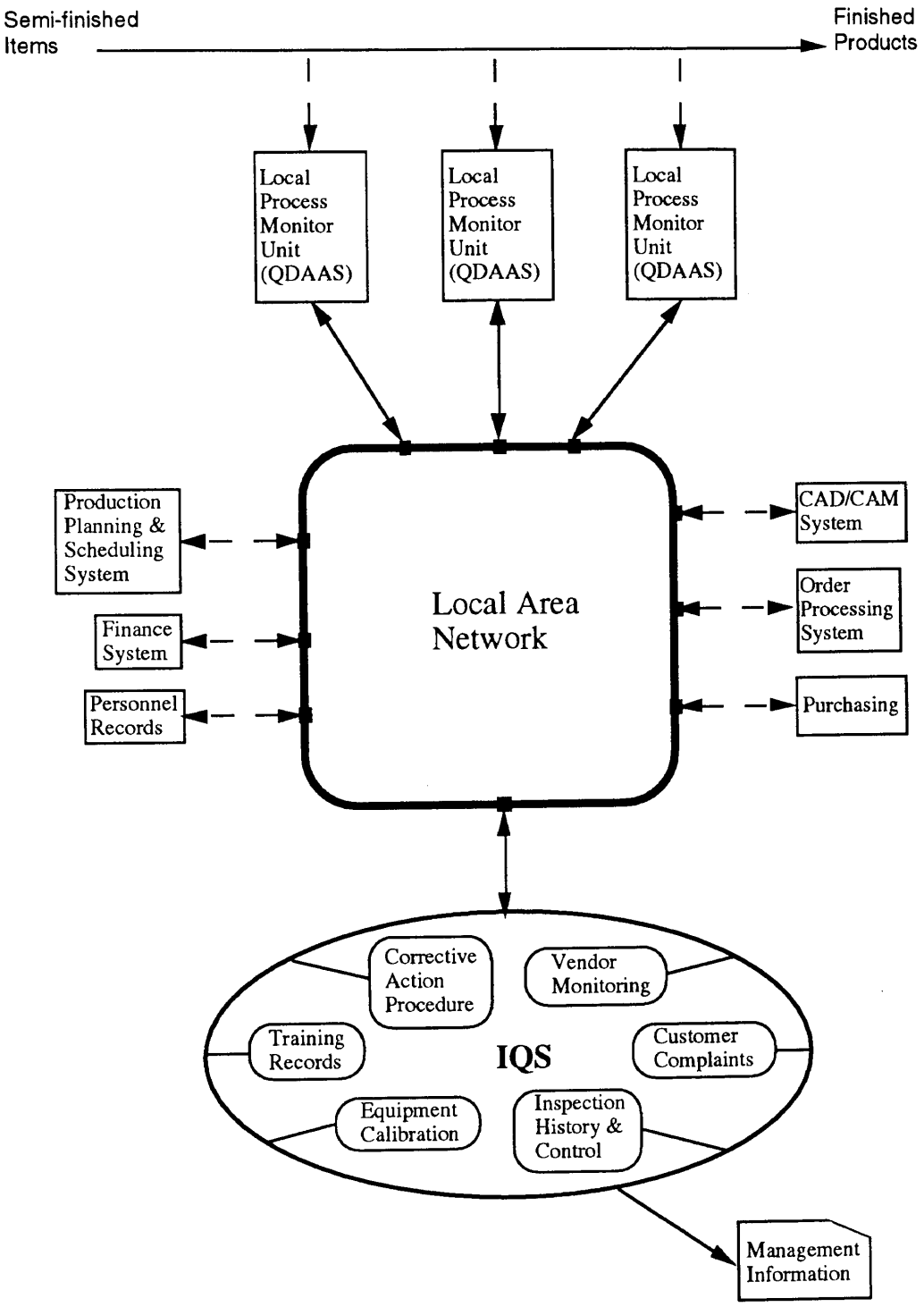


Figure 10.2: Schematic of the Extended Prototype

10.3 The Active Element

In addition to the menu-driven user interface, the CQDB must be able to communicate information between the various physical parts of the integrated quality system without the necessity for direct human intervention. This can be effected by means of a set of continuously running active processes to carry out a selection of tasks. These processes have been given the collective title the "Active Element" which will be used in the following description. Tasks 1, 2, 3 and 4 below are deemed to be vital even in the simplest possible implementation of the IQS, whilst the remaining functions will become necessary as the IQS develops in complexity:-

1. The CQDB obtains the production schedule from the production planning system. It then selects the necessary inspection specifications for all work orders planned for the forthcoming production period and down-loads them to the local quality monitoring workstations which are expected to carry out the inspection.

2. An operator at a local quality monitoring workstation requests an inspection specification to govern the inspection of a stated work order. The workstation advises the CQDB which selects the specification and down-loads it to the requesting workstation.

3. When a QDAAS encounters an end of batch, it formulates a summary quality report which it up-loads to the CQDB. When all necessary inspections have been completed for a given batch, the CQDB generates a certificate of

conformance for it. Any batch which is failed as a result of some inspection will become the subject of a Corrective Action request and no certificate will be generated unless a concession is issued during the corrective action procedure.

4. If the CQDB receives a user request for information concerning a batch which is still active, it requests an interim batch summary report from the quality workstations which are inspecting the batch. This is then up-loaded to the CQDB and delivered to the requesting entity, whether this be a human user or another information system.

5. Activating time-dependent activities within the CQDB (eg. regular reports, instrument calibration schedules).

6. Communications and data exchange with external computer systems such as production scheduling, design and commercial.

10.3.1 Design and Implementation of the Active Element

The functional specification set out above was formulated jointly by the members of the project team. When these functional specifications were decomposed it became clear that a set of distinct processes, each having a well defined functional role, could be identified, with many of these processes being common to several of the higher level functions previously defined. It was therefore decided that the Active Element could

best be implemented by devising a method for flexible linkage of these processes to suit the needs of each high level function, rather than by implementing the high level functions as complete functional entities (as might be implied by the specification above). The activities of these processes were likened to the roles of servants (or flunkeys) in a large household (for example, housekeeper, butler, footman). As the functional design progressed, this analogy was used to provide easy identification of the processes which interacted to carry out a given task. Thus the processes (known in UNIX terminology as Daemons) comprising the Active Element are referred to herein by these names.

All the Flunkeys (ie. the functional processes comprising the Active Element) were implemented in Pro-C (a C pre-processor which provides an interface into the Oracle DBMS by means of SQL commands imbedded in C code). The central actor was the "Housekeeper", who monitored an Oracle database table known as the Noticeboard, and, by reference to a second Oracle table, caused other flunkeys to run so that tasks might be carried out as required. The "Housekeeper" daemon ran continuously, while the others were activated only as they were needed. The "Housekeeper" and other flunkeys were implemented by this author, with the exception of the process known as the "Butler" which was implemented by Wort and is only described herein for clarity of explanation of the Active Element as a whole.

10.3.2 Flunkeys Employed by the Active Element

Housekeeper: monitors the noticeboard and causes the activation of flunkeys in response to notices which are placed on it. The Housekeeper's reference table tells the Housekeeper how to react to each type of notice, thus the introduction of a new function to the Active Element requires no change to the Housekeeper program, nor to any other flunkey, but is implemented by the development of a new special purpose flunkey to carry out the required function and the addition of relevant notice types to the Housekeeper's reference table.

Footman: carries out selection of required inspection specifications from the CQDB and presentation of specifications as a UNIX file ready for collection by the Butler for delivery to a QDAAS. There are two kinds of Footman; one to action requests for single identified inspection specifications, and the other to provide sets of inspection specifications for the forthcoming production period.

Cleaner: removes redundant notices from the noticeboard table and deletes temporary files on the completion of data transfer activities.

Clerk: generates documentation such as Certificates of Conformance.

Maid: carries out periodic activities as initiated by the Timekeeper. A set of special purpose Maids exist to undertake such activities as a) checking for unacknowledged or uncompleted complaints, b) issuing warnings for equipment about to require calibration,

c) produce lists of orders due for delivery, d) produce lists of overdue payments, invoices or orders.

Reporter: generates interim batch reports.

Porter: data transfer of inspection results between QDAAS files and CQDB tables.

Tradesmen: a set of daemons which communicate with external systems. For example, obtaining production schedules (this activity may by initiated either by the Timekeeper or via the user menus), transferring inspection specifications from design into the CQDB.

Butler: communication between QDAAS and CQDB. This includes file transfer and the placing of messages on the noticeboard.

Timekeeper: monitors passage of time and initiates time dependent activities (eg. daily, weekly, annually) by placing the necessary request on the noticeboard. The operation of the Timekeeper is somewhat similar to the Housekeeper in that its actions are also governed by database tables rather than by program modification, so that it is only necessary to add a record to the Timekeeper's Diary stating the desired wake up time and the request to be placed on the noticeboard to make an activity time triggered.

10.3.3 Control of the Active Element

The Noticeboard table is used to communicate activity requests and acknowledgements between the various daemons. It is continuously monitored by the "Housekeeper" and, together with the Housekeeper's Reference table, controls the operation of the Active Element. When there is a need to modify the system, for example to add an additional function, this may be done without altering the existing processes, simply by writing the required Pro-C programs to implement the new function. These programs are then integrated into the Active Element by adding extra records to the Housekeeper's Reference table to control the sequencing of their activation to carry out the desired new function.

Thus messages such as the following examples may be placed on the noticeboard:-

1. Request placed by the "Butler" on behalf of a named QDAAS asking the CQDB for inspection specifications for current production period.

2. Request placed by the "Butler" on behalf of a named QDAAS asking the CQDB for inspection specifications for stated work order number.

3. Notification from the "Butler" of delivery of an end of batch summary to the CQDB.

4. Notification from a "Footman" to the "Butler" that requested inspection

specifications are ready for collection by a QDAAS.

5. Acknowledgement from the "Butler" that specifications have been collected by a waiting QDAAS.

6. Acknowledgement to a QDAAS from the "Porter" that a batch summary has been successfully assimilated into the CQDB.

7. Request from menu driven part of the CQDB to a particular QDAAS for an interim batch summary. This might also be used where a "Tradesman" requires such a report to satisfy a request from an external system (eg. production scheduler).

8. Notification from the "Butler" to the CQDB that an interim batch summary has been delivered and is ready to be actioned by the "Reporter".

9. Communication with external systems identifying either the need for, or completion of, action by a "Tradesman". There will be a number of different notices relating to the activities of "Tradesmen" according to the interfacing requirements of the systems with whom links must be established.

10. Initiation of regular periodic tasks (eg. generation of monthly or weekly reports) at the instigation of the "Timekeeper".

10.3.3.1 Noticeboard Table Structure

The Noticeboard Table facilitates communication between the various processes of the Active Element. Each communication has three principal features:

a) a 2 character code which defines the type of notice,

b) a 30 character free format detail section which may be used to pass any parameters necessary for the performance of the required activity,

c) an identification code to indicate the sender or receiver as appropriate.

10.3.3.2 Housekeeper's Reference Table Structure

The purpose of the Housekeeper's Reference table is to define the action to be taken by the "Housekeeper" in response to an item appearing on the Noticeboard. It is this table which is key in providing the flexibility which underpins the whole of the Active Element.

Type of Notice	2 characters
Action to be taken	30 characters
Flunkey to be Called	10 characters
Do Nothing Indicator	1 character
Next Notice	2 characters

The "Do Nothing Indicator" is used where the notice is addressed to another flunkey

(for example, the "Butler") and shows that the "Housekeeper" need take no action in response to this notice. The "Next Notice" field is used where the Noticeboard must be updated as an activity progresses.

10.3.4 Detailed Functional Specification of Active Element Tasks

In order to illustrate the interaction between flunkeys, Appendix 3 presents detailed functional specifications for some of the Active Element tasks identified earlier in this chapter.

10.4 The Complaint Monitoring Module (CMM)

The CMM was developed from an existing, but quite simple, free-standing PC-based system. The expeditious handling of customer complaints was considered a high priority at the test site, even though the volume of complaints was low, because the company were keenly aware of the potential for damage inherent in a dissatisfied customer.

The main table of the CMM contained the detail of the complaint and, most importantly, the date on which it had been received and the date when a response to the customer had been made. On receipt, the complaint was coded against a set of complaint descriptions held in a lookup table. To create this table, a review of past complaints was undertaken and, after analysis, a list of "standard" complaint descriptions was composed. In addition, the Quality Manager drew up a supplementary list of possible failures which had never been reported, but could occur. In the event

of a complaint arising which did not fall into any of the categories in the table, extra entries could be added. The complaint was then investigated so that a solution to the customer's problem could be speedily implemented. Meanwhile, a rough calculation of the cost of the complaint was made. This gave a feel for the severity of the complaint, although many factors, such as disruption of the customer's activities, could not be estimated. Next, the details of the complaint were used to activate a full investigation. In a full IQS, this would cause the initiation of an investigation by the CAP system, but this did not happen in the prototype because CAP module was not implemented.

The CMM provided several standard reports; a list of complaints awaiting investigation ordered by date of receipt, summaries of types of complaint and mode of failure selected by date or product, and a list of finalised complaints including action taken to satisfy the customer.

10.5 The Corrective Action Procedure (CAP) System

The CAP system was developed through a close cooperation between the Quality Manager for the test site and this author, with the entire team responsible for the implementation of CAP on the site becoming involved once the draft design had been worked out. This process is described in detail in chapter 11.

10.5.1 Operation of the CAP System

The CAP system is controlled by a site CAP team which is responsible for monitoring

the status of CAP's, planning investigation and action, and assigning staff to carry out the planned tasks. Particularly urgent CAP's can be expedited by "Chairman's action", followed up with full team consideration of the long-term implications of the CAP.

CAP's may take several months (or even a year) to be fully implemented. The CAP team produce a schedule for the CAP and carry out regular reviews of progress. On completion, the CAP is audited against the schedule to proposed actions laid down by the CAP team.

A problem which has a CAP raised against it is not viewed as a non-conformity, but is considered to be under control. A CAP could therefore be considered to be a concession.

Any CAP recording system (computerised or otherwise) must be able to relate a newly proposed CAP to all existing CAP's, whether active or closed, so that additional information is added to the appropriate active CAP if the new CAP duplicates it. Should the new CAP overlap, but not fully duplicate, an existing active CAP, that CAP may be extended; alternatively, the new CAP may be split, leaving only the completely new element as the subject of a free-standing CAP. Also, where a relationship is established with a closed CAP, a link must be made so that the historical information gathered in the course of actioning that CAP will be made available to the new CAP to avoid duplication of effort. This will be necessary whether the new CAP is found to demonstrate the failure of an earlier solution, or where the new problem shows

similarities to an earlier, but independent problem, such that a solution successfully applied in one area may be adapted or transferred to another. Finally, it is vital that the initiation of a CAP be easy, so that any person or department will be encouraged to raise any matter of concern to them as a CAP.

The lifecycle of a CAP is as follows:-

1. CAP raised against some problem.
2. An initial response is given.
3. CAP team produce action schedule and assign investigation priority.
4. As actions are carried out they are reported.
5. CAP is audited against schedule.

Throughout the lifecycle, the CAP is reviewed by the CAP team, who may adjust the priority in the light of other active CAP's.

10.6 The Vendor Monitoring Module (VMM)

The VMM of the prototype IQS is limited to three functions:

a) The maintenance of a list of approved vendors for stated goods which will be used by the purchasing department.

b) The recording and analysis of any variance between promised and actual delivery dates for incoming goods.

c) The provision of the ability to match up inspection results, in particular from incoming goods inspections, with the supplier of those goods, via the inspection control module. Because of the lack of full traceability, such matching will almost certainly be incomplete where multiple vendors are contracted to supply a particular item, but nevertheless, useful information on vendor product quality will still be provided, thus allowing feedback to vendors, and hence, giving the opportunity for collaborative improvement activities, or, in the worst cases, for the discontinuation of orders to that vendor, who may then be removed from the list of approved suppliers.

The value of the VMM lies in the ability to assure the quality of those items which are to be built into the organisation's finished product, for good design and well controlled working practices can be completely undermined by the inclusion of poor quality parts and raw materials. Ultimately, the quality of a product is only as good as the quality of its poorest component.

10.7 The Training Records Module (TRM)

The prototype TRM had at its core three data tables. The first held only staff names and the departments in which they worked. In a fully integrated IQS this table would

be replaced by a link into the personnel system. The second table contained details of available courses, including duration and location, number of modules, trainer and an abstract of the course content. The third table recorded training history and held staff name, course reference (which could then be linked to the details in the course table), start and end dates and finally, a flag to indicate successful completion. In addition, details of trainer organisations were held in the company approved supplier file.

This structure allowed the production of a variety of useful reports; for example, the training history of an individual member of staff, for all staff in a given department, lists of staff studying on uncompleted courses, lists of courses commenced since a stated date, lists of available courses from approved trainers.

However, while very useful, these did not fully satisfy the requirement. It was therefore necessary to extend the TRM. The first modification was to allow the monitoring of progress through multi-module courses, so that the student's records clearly showed successful completion of each module, whilst indicating those modules still to be undertaken. This was achieved quite simply by extending the course table and recording each module as though it were an independent course, with its own reference code formed by concatenating the master course reference with the module number. When a member of staff was registered for a multi-module course, the TRM recognised this from the module number field and caused the full set of modules to be selected and presented to the user for acceptance into the training plan or rejection. This allows the inclusion of courses with elective modules.

The second extension was to allow the specification of compulsory or precluded courses according to department or even job function (this required the addition of job function to the staff table). This was achieved by the introduction of an additional data table which recorded course reference, department of job function and whether compulsory or precluded. This table was fairly small, as this situation applied to only a very small number of courses. An additional report was defined which cross checked individual staff records for any relevant departments or job functions to be compared against the new table and a list of discrepancies produced.

The TRM required two links with other modules, these being CAP and ECMM. The link with the CAP system was to allow new courses and trainers to be added to the approved list. The link to ECMM seems, at first sight, rather anomalous as staff are not normally deemed to be equipment. However, in some fairly rare cases, there is a requirement for qualifications to be renewed by means of a refresher course after a certain period of time has elapsed. Since this is exactly the criteria on which the ECMM operates, it was felt that its use for the monitoring of renewable qualifications was a much better solution than the development of a special purpose module.

10.8 The Equipment Calibration Monitoring Module (ECMM)

A stand-alone PC-based calibration system was already in operation at the test site. This system provided all the necessary functionality for control of equipment calibration, but did not address the issue of training and certification of users. The solution proposed was the integration of the existing system into the CQDB, where it could be extended

and linked to the Training module described above by means of a set of registers detailing the training and certification requirements of each piece of equipment. These registers could also be used where there was a similar need to control the operators of other, non measuring, equipment.

The ECMM was required not only to keep track of the next due data for the calibration of a given piece of equipment, but also to determine the appropriate staff member or external agency to carry out that calibration. To do this it was necessary to check the currency of that person or agency to undertake that calibration had been maintained and was up-to-date.

To further complicate matters, the date of next calibration was not always simply a matter of calculating a certain number of calendar months from the last calibration, but might, for some items of equipment, depend on the item's usage. Thus, it was necessary for the ECMM to log when a given piece of equipment was issued from stores and for how long, so that total usage since the previous calibration could be calculated. It was also necessary for the ECMM to check that certain equipment was issued only to a staff member who was properly authorised to use it, although this requirement applied only to a small sub-set of equipment.

In order to assure the validity of inspections it was also necessary that details of the measuring equipment be recorded, so that cross checking with the ECMM could be undertaken to prove that all equipment so used was demonstrably in proper calibration.

10.9 Traceability

The prototype IQS does not provide a specific traceability function, however, a very limited level of traceability support can be provided by the prototype IQS through the inspection control module. This can be extended to some degree by means of links with vendor monitoring, order processing and production scheduling. However, this has not been explored during this project as the test site had no requirement for traceability.

Although it will be necessary for this complex area to receive further attention if the IQS concept is to be adopted by any industrial sector where traceability is an issue, the design of the prototype IQS is such that the addition of functionality to provide traceability should not require significant structural revision.

10.10 Product Liability

Support for Product Liability defence is by no means complete in the prototype IQS, however, data from the inspection control, corrective action, calibration, vendor monitoring and training modules may be combined to provide a reasonable level of coverage. This was not considered to be a priority function by the test site, whose product is not likely to be safety critical.

10.11 Inter-System Links

Although links were established between the internal modules of the prototype IQS, it

was not possible to do more than simulate (in a very simplistic manner) the links which should exist between the IQS and other data holders in the organisation. The reasons for this were three-fold; firstly, the financial resources of the ACME project were not sufficient to purchase and set up other manufacturing information systems in the laboratory; secondly, such systems already in use at the test site could not be linked because there was no network on the site, and with a new site being built, the necessary investment to install one for the relatively short period before the move could not be justified; thirdly, the development effort necessary to design and implement such interfaces was far too great for one person working only part time on the task.

It is unfortunate that this element of the IQS could not be prototyped within this study. Figure 10.3 shows the architecture suggested for the core of the fully functional IQS to be implemented under the Marquis Esprit proposal described in chapter 12. This structure is the result of several discussions between this author and four other members of the Marquis team. It is believed that a system core of this form would provide the interfacing and control necessary to achieve the IQS functionality defined in this thesis. However, it is hoped that funding will become available in the near future to test this belief and to investigate the other items identified in chapter 12.

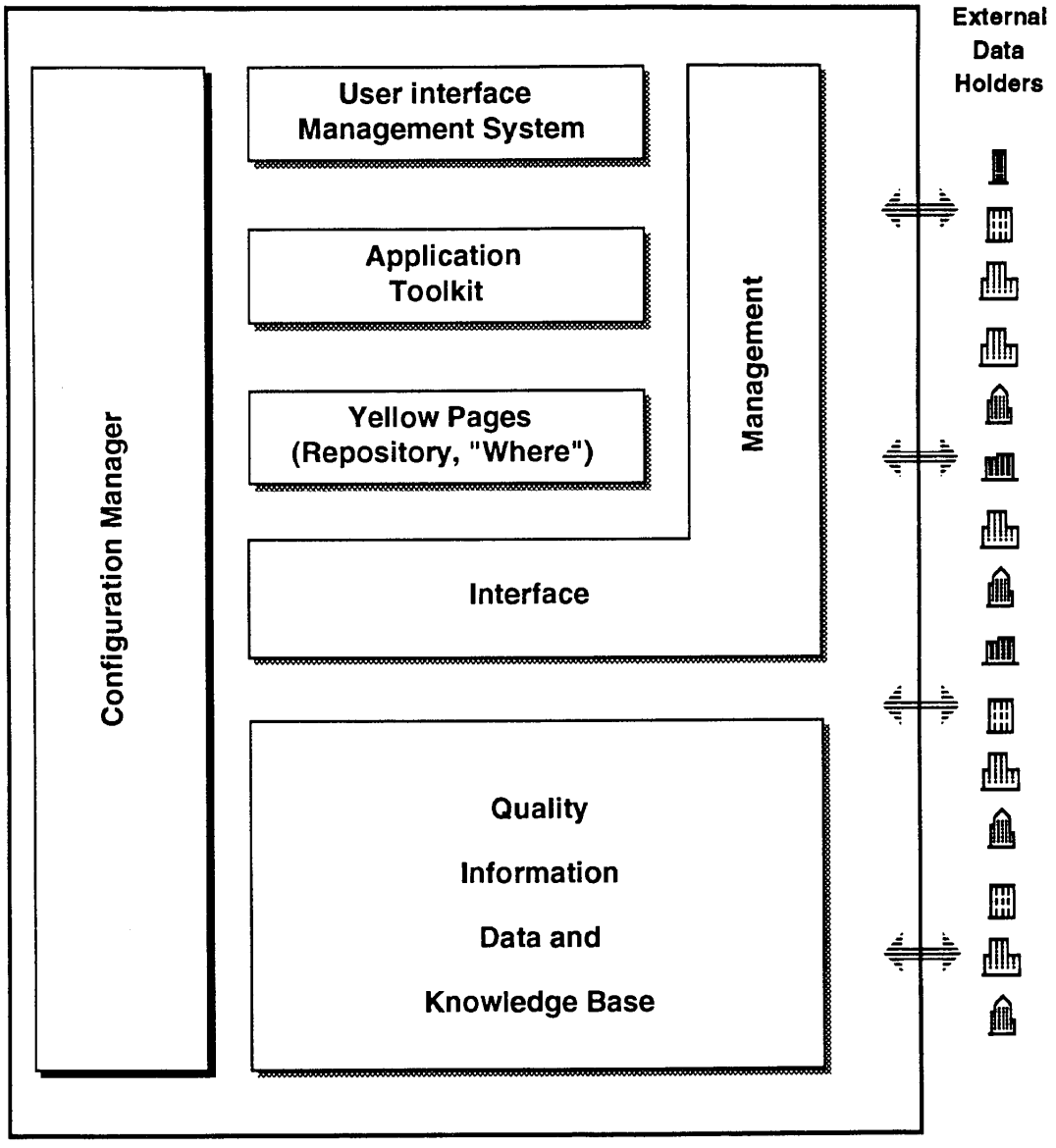


Figure 10.3: Proposed Architecture for the Marquis System

Chapter 11

Software Development Techniques

11.1 Introduction

Fairly early in the development of the prototype IQS, it because apparent that the best architecture for the system would be highly modular, with a consequent high degree of independence between the development cycles of the various modules. Thus it was decided that it would be interesting to use different methodologies during the design and implementation of the various modules. Although this was not a core element of this investigation and could not be considered to be sufficiently rigorous to stand alone without further work, the results of this small trial proved quite interesting and are therefore reported in this chapter.

11.2 Comparison of Development Techniques

The bulk of the IQS prototype was fabricated by means of a cycle of prototyping and review where, in each cycle, some element of the specification was clarified so that the next generation of the software more closely satisfied the users' needs.

In order to investigate the relative merits of different software development techniques, two modules of the CQDB were designed, implemented and tested using different approaches. One (the Training Records and Planning module) employed traditional systems analysis and specification methods in its development. Whilst the second (the

CAP system) was evolved through a close working partnership between client user and analyst.

The factors considered in this comparison were:-

1. User satisfaction. How well did the finished system live up to the expectations of the users?

2. Total development time.

3. Degree and spread of user involvement throughout the development cycle.

4. Changes in user requirements from the original specification or request to the final system.

5. User enthusiasm for the project. How did this vary throughout the development cycle?

11.3 Independent User Specification - The Training Module

In the case of the Training Module, this author requested the client user to produce a module specification which was then implemented without change and evaluated against both the requirements of BS 5750 and by detailed discussion with the user so as to

judge the quality of a specification provided by an unassisted user. The author was careful not to influence or comment upon the developing specification at any stage. The results of the module evaluation are described below and demonstrate clearly that client users, even when they have IT experience, require considerable support from their analyst as they seek to define their requirements, if they are to produce an accurate specification which will result in a system which exactly meets their needs.

Initially, a specification for the Training module was proposed by the Test Site. They wanted to be able to enter information concerning both training previously received and that planned for the future for each person, see what training had been completed and assess the training done in each area. They needed to enter training needs and check to see when these have been satisfied, also to determine training done in a specific period. In addition, it was deemed necessary to keep records of courses which have been used and who they were conducted by, both for internally run courses and external trainers.

A number of deficiencies were evident in the initial version of this module which was based wholly on a specification produced by the user without consultation with the analyst. This highlights the problem of obtaining an accurate and complete specification from a user (discussed in the next chapter). The user in this case was not typical of those most usually encountered during the design and development of new systems. Users typically have little or no experience of the specification of computer programs, and often have not had much practical interaction with computers. The user

who specified the training module is most unusual in that she is known to have received formal training in programming and system design.

The deficiencies identified were:

a) Details of available courses. The system must be supported by procedures to review the diet of courses recorded as available and approved. It is necessary to carry out regular reviews of the training needs of the organisation as these will not remain constant; to monitor the performance of training providers to ensure that course quality is maintained; to remove obsolete courses; and to investigate new courses and training organisations as they become available, and where appropriate to instigate the approval process so that they may be added to the list of available training resources.

b) Progress through long courses. The specified data structure did not provide any means of recording when someone was part-way through a modular training course. This may be significant where the student accumulates module credits over a long period. For example, the Institute of Quality Assurance professional exams which comprise five modules taken over a two year period, or the Integrated Graduate Development Scheme (IGDS) modular MSc scheme where 12 modules and a project must be completed over a period of two or more years, and where credits may be accumulated from modules run by a number of different higher education establishments.

c) Educational history and experience. The plan of courses to be taken by each member of staff shows which are outstanding, in progress or completed, but does not include any provision for recording existing qualifications or experience.

d) Compulsory and restricted courses. The initial data structure did not make any provision for courses which may be either compulsory for, or restricted to, a particular department.

e) Currency monitoring. In some instances there is a requirement for regular re-examination or monitoring to maintain the currency of a qualification. For example, First Aiders must undertake refresher courses at regular interval; staff certificated to carry out certain types of inspection must have regular eye tests to ensure that their vision is adequate. It is therefore necessary to record both the action to be taken and when it must be done. Clearly it is desirable that action is initiated far enough in advance of the deadline that the necessary action can be taken before the qualification or certification lapses, as this may require a complete repeat of the initial training and examination as if it had never been done before, whilst in the meantime, the person will be precluded from doing the related task. The issuing of this warning may be implemented by means of the Timekeeper Active Element described earlier.

None of the items discussed above were difficult to implement, although they did

require certain modifications to the operational procedures followed by the staff responsible for these personnel matters. Furthermore, the links to other data which the IQS makes possible provide added benefits with respect to the investigation of causes of failure in product, process and system, as well as streamlining the improvement process when staff skills must be updated.

11.4 Analyst and User in Partnership - The CAP system

The CAP system specification was developed using the **traditional design review** approach with analyst and client user working closely together. **For the reasons explained in chapter 9, this module was never fully implemented at the test site,** but simulations carried out in the final stages of the design process were used to verify the design. There was also firm evidence of strong commitment to the CAP module from all those involved in the design process, with even those who had only limited input during the later stages having developed a clear sense of ownership.

The Du Pont Electronics Corrective Action Procedure (CAP) was developed in response to the requirements of the Quality standards ISO 9001 and BS 5750 (paragraph 4.7 Corrective action). It was designed jointly by the author and the Du Pont Electronics Quality Manager, and was then presented for review by the Du Pont team who were to implement it at the Bristol site.

The design process involved very close collaboration between user (the Du Pont Quality

Manager) and analyst (this author). It comprised the following stages:-

1. Presentation of the perceived requirements of the standard by the user.

2. Review of a similar system known to be in operation at another Du Pont site.

3. Identification of issues which might impinge on the running of the new procedure. The major area discussed under this heading was the unusual management structure under which the Bristol site operates (this was examined by Harwood [51]).

4. Proposal of an outline sketch of the new procedure by the user.

5. Extensive discussion of the details of the new procedure. This took place during a series of meetings, and was very much an iterative process.

6. Trial of the proposed procedure. This was accomplished by the user and the analyst carrying out a "dry run" by applying the procedure to a known problem.

7. Minor revision of the procedure as a result of the dry run.

8. Production of a full draft to the proposed CAP, including all associated forms.

9. Presentation of the proposal to the full CAP team.

10. Review of the procedure by the full CAP team leading to detailed discussion and revision until all were satisfied that the procedure could be made to work in practice.

11. Formal acceptance of the procedure by the CAP team.

12. Development of implementation plan and agreement of implementation schedule.

13. Implementation (including training and CAP launch).

14. Full review of CAP after a period of operation.

The reasons for stages 9 to 11 were twofold; firstly as a Quality Assurance measure to ensure, as far as possible, that the proposed procedure was correct and really did match the requirements both of the Quality standards and the company. Secondly, as a means ensuring that the full CAP team were committed to a proposal in which they could repose confidence. The changes made during stage 10 were, for the most part, cosmetic in nature, being concerned with the reaction to and acceptance of CAP by the workforce as a whole. However, it is significant that the CAP team also identified a section of the procedure which would not have worked smoothly in practice and proposed an alternative approach, which was then tested by simulation. This

demonstrates the importance of this type of user review to ensure the correctness of the proposed solution before implementation.

11.5 Comparison

The principle difference between these two development cycles was the timing and amount of input from the analyst. In the case of the Training Records module the analyst remained aloof during the development of the specification and then simply implemented exactly what was specified, while for the CAP system analyst and client worked together in close partnership throughout the specification process and into an evaluation of a rough prototype.

Finally, to a consideration of the five comparison factors set out in section 11.2.

11.5.1 User Satisfaction

Even though the CAP system did not achieve full implementation, the heavy user involvement in the later stages of the design in combination with the results of the final simulation suggest strongly that this module would have given a high degree of user satisfaction. In the case of the Training module, once the inherent deficiencies had been identified and corrected, the module performed quite satisfactorily. Thus, in terms of ultimate user satisfaction, little difference was found between the two methods.

11.5.2 Total Development Time

This is somewhat difficult to compare fairly because the CAP system was inherently rather more complex than the Training module, and obviously also because the CAP system was never fully implemented. However, due to the need to keep returning to the specifying user for clarification and alteration of the specification, and the consequent need to make alterations to the module, the total development time for the Training module was greater than that of the CAP module by a sufficiently large margin to suggest that, even allowing for the necessary extra effort to complete the CAP system, taking into account the difference in module complexity, the partnership method was more efficient.

11.5.3 User Involvement

With the Training module the user involvement was restricted to the single user who wrote the specification and did not include any other staff from the site. Interaction between user and analyst was very formal and this factor did not encourage the development of a rapport between the two parties. In the development of the CAP module, on the other hand, the lead user and the analyst work very closely together for the entire duration of the project and greatly benefited from the establishment of a strong cooperative relationship between the two. The inclusion of the entire CAP team at stage 9 of the development process provided a very necessary quality assurance element whilst also ensuring good user acceptance. On the negative side, it should be noted that with this method, the core members of the team may become somewhat

protective of their "baby" when it is presented to the full team, and may therefore be rather on the defensive in the face of criticism. It is important to be aware of this potentiality and guard against it in order to gain the greatest benefit from team involvement.

11.5.4 Changes From Specification

The specification for the Training module required major revision to correct the identified deficiencies. Whereas the CAP system specification was subject to only minor, largely cosmetic changes, with the exception of one procedure which the CAP team felt was not in keeping with the mode of operation at the plant.

11.5.5 User Enthusiasm

There was a marked difference between the two modules in this respect. The user involved with the Training module saw a clear need for the module, but never really got excited about the prospect of the new tool. The CAP team, however, not only saw the need, but appeared to be filled with a desire to see the CAP system up and running. This was evidenced very clearly by their reaction to the news that the system was not to go live. This is especially significant when one considers that, when the news broke, the entire team were all aware that their jobs were very much at risk. The early stages of the development of the CAP module were driven forward by the great enthusiasm of the lead user; subsequently this was enhanced by the reception of the proposal by the

full team who, when they bought in to the idea, also became very enthusiastic.

11.6 Conclusions

Although it is dangerous to draw and firm conclusions from such a small and simple investigation, the findings suggest strongly that the partnership approach resulted in high levels of user enthusiasm and involvement, culminating in satisfaction with the finished system, along with a minimum number of changes to the specification during the development cycle. There is also a suggestion that the total development time may be reduced, although this is not proven in this case.

In comparison with the evolutionary prototyping (EP) approach used for the rest of the system, certain points may be noted.

a) In common with the partnership approach, EP relies heavily on the involvement of users. Even when the initial specification had been created through a formal analysis process, such as the studies by Tannock and Harwood (mentioned previously), user enthusiasm can be stimulated when the opportunity to examine and criticise a prototype is linked with a knowledge that their response will influence the final state of the software. As with the partnership method, this leads to the creation of a feeling of ownership, and thus to better user acceptance and satisfaction.

b) It is not at all clear that EP in any way reduces the number of changes made to the original specification during the development process; indeed, it seems likely that it may actually increase the incidence in the early cycles. However, this seeming disadvantage may lead to significant cost savings by ensuring that necessary corrections are identified and carried out in the early stages of development, rather than after full implementation and delivery; the most expensive time to make changes. Furthermore, the expense of making modifications at the end of the development process is likely to result in a situation where users are forced to live with a system not entirely to their satisfaction because of the expense of correcting any but the most significant non-conformances.

c) In regard to total development times, no judgement can be made on the basis of this study as no significant variation from expectation were noted. However, the shifting of modifications from the later to the earlier stages of the process is bound to have the effect of reducing the total effort required to achieve a satisfactory end result.

Chapter 12

Conclusions and Further Work

12.1 Evaluation of the Prototype IQS

The prototype IQS implemented during the course of this work was evaluated in the laboratory by a quite broad spectrum of users from the Du Pont Test Site, ranging from technicians to middle management, and was found to be functionally adequate to meet the basic quality support needs of the organisation. In addition, a stand-alone version of the menu-driven prototype was installed on a PC at the test site. The main features of this version were the Customer Complaint module and an early version of the Training Records module. Although a wider range of possible options were present on the system's menus, many were non-functional but did serve to show the users what features were likely to be offered by a more complete implementation. One pleasant surprise which arose from this exercise was the easy with which the prototype was ported from the Unix workstation on which it was developed to a PC at the test site. However, the more extensive on-site testing originally planned was precluded by the closure of the site. Furthermore, it would have been desirable for the prototype implementation to include at least one fully functional link between the IQS and some other manufacturing information system. Unfortunately, a lack of resources made this impossible in the laboratory, while the lack of a LAN prevented development at the test site. Hence, the proposed inter-system links have only been simulated.

12.2 Reflections on the Proposed IQS

The study of quality makes clear that the goal of Total Quality in all aspects of organisational activity is reliant on two factors. The first is the total commitment of the entire workforce, from senior management to manual and service staff. The second factor is the ability to judge accurately the quality health of each and every activity, so that improvement efforts can be properly targeted and designed with full knowledge of the conditions pertinent to the identified area or process.

Much work has been undertaken to address the first factor. However, most work in the second area has been focused on data acquisition and information in well bounded sections of the quality activity (for example, Mellichamp et al [89], or the computerisation of SPC). There are some isolated cases where individual organisations have made serious attempts to develop comprehensive quality information systems which span the whole gamut of quality activities (Wolfe and Tassé [148], Turconi [138]), but rarely is direct linkage with another element of an integrated manufacturing system described. Lee-Mortimer [77] describes the system introduced by Presswork (Metals) to replace their manual records system where links have been established between their "Total Quality Management System" and their Integrated Manufacturing system but interaction is limited. Very much closer to the IQS proposed herein is the Quality Control Information system (QCIS) described by Lin [78]. This uses a distributed database to integrate various stand-alone quality management activities and has data gathering links with other systems in design and manufacture. By providing a knowledge model, QCIS adds value to the data it holds by describing the dynamic

aspects of the information, including its functional capabilities. It holds knowledge about emerging quality problems and rules for how to structure quality related solutions. This is presumably built gradually from past case histories, although whether the knowledge is held in some type of expert system or in a simple database is not stated explicitly in the paper. However, despite its strong conformance to the IQS concept, QCIS is not truly a Total Quality support system because it has no links to systems not directly concerned with production.

In the realm of ready-made products, a number of software houses offer quality documentation and information systems (Appendix 1 contains brief descriptions of a representative sample of these products). Some of these provide extremely good coverage of the necessary functional areas, but all are free-standing systems which do not link with existing information systems and so cannot fulfil the central role of data integrator deemed so important by this author. Little consideration has been given to the task of integrating the many disparate information systems which already exist, in order to add an extra dimension of usefulness to these often expensive systems, and to provide the information necessary to truly support and focus the human activities of quality assurance and improvement.

Under TQM, the IQS is required to take an interest in **all** areas of company activity. This leads to significant overlap with existing systems (eg. financial, MRP, commercial and personnel). The IQS must therefore be built around certain core elements linked to a number of independent external systems. These external systems may be already

in place in the organisation, prior to the introduction of the IQS, and may be running on different hardware and be written in other languages. Hence, the IQS must address the practical problems of acting as a communications nexus for a heterogeneous set of existing systems. The IQS should neither expect nor require any changes in these existing systems in order to facilitate data exchange.

The IQS can be implemented gradually, with each component forming an "island of data automation" until full integration is achieved. Thus modular design is vital to address the problems presented by the sheer scope of the IQS. Secondly, modularity provides a means of customising the system to suit the needs and budgets of many organisations, both large and small. Further, it should be noted that small and medium sized organisations are most likely to benefit from a flexible, modular commercial implementation of the IQS, for while they do not have the resources to do the job themselves, they may be under pressure, both from large customers and competition in the marketplace, to not only improve product quality, but also to provide information as evidence of the efficacy of their quality system in order to satisfy contractual requirements imposed on them as a condition of continued custom.

The usefulness of the IQS could be significantly increased by the addition of knowledge based (expert system) techniques, as a means of improving the effectiveness of the quality system as a whole. An IQS which included artificial intelligence in certain modules would have the potential for initiation of quality improvement activities, rather than simply acting as a passive data server. This development path clearly holds great

potential for the future, although it has not been investigated herein. It is hoped that future work in this area will be possible under the auspices of the ESPRIT programme.

The Active Element provides the necessary mechanism for certain activities, in particular those relating to data exchange, to be initiated without direct user intervention via the menu-driven user interface. This is desirable for two main reasons; firstly, because it removes a distracting responsibility from the user, and secondly, because it allows the IQS to react without delay when one of a set of pre-defined circumstances arises, rather than having to await human instruction. Furthermore, the Flunkey methodology has application beyond the remit of the IQS, for it could be used to facilitate a wide variety communication activities in a distributed data environment.

The flexibility provided by the Noticeboard, Housekeeper's Reference Table and Timekeeper's Diary will permit easy adjustment or extension of the IQS as further links to external systems are established. As currently implemented, all the functions of the Active Element are dependent on the set of pre-defined responses given in the Housekeeper's Reference Table, however, there are circumstances when it would be desirable for the Active Element to have some reasoning ability to allow it to select between several possible courses of action when responding to a notice. This could be achieved by replacing the Housekeeper's Reference Table with an expert system.

With regard to the revised IQS architecture laid out in Figure 10.2, the basic functional elements of the prototype IQS still exist but will undergo a metamorphosis as follows:

Active Element: The existing Flunkeys form the basis for the Integration Manager, although clearly there will be a need to implement a quite large number of additional Flunkeys to provide all the required interfacing functions to link the IQS core with the rest of the IT base across an organisation.

The Housekeeper's Reference Table provides the core of the Yellow Pages directory which has the responsibility for identifying the location of data and the appropriate access method, thus directing the activities of the Integration Manager.

Quality Tools: The tools provided in the prototype (eg. Customer Complaints, Vendor Monitoring, etc.) will reside in the Applications Toolkit, along with such things as statistical packages and RA-IQSE. These modules will not hold data locally but will access it through the Yellow Pages and the Integration Manager.

Quality Data: Following analysis of existing IT systems and the production of a data dictionary for a given organisation, identified items of data for quality use will be partitioned so that only such data as is not held in any other accessible IT system in the organisation will be held in the IQS's own database. The local database will also house an Artificial Intelligence capability to provide the IQS with some degree of decision making capability.

12.3 Practical Difficulties to be Overcome

The prototype IQS described herein has been used as a vehicle to explore a limited number of aspects of a global quality information server; it is not however a useable product suitable for installation as a live system. Before this becomes a feasible reality a number of difficulties must be overcome.

12.3.1 Integration

In order to truly satisfy its functional requirement the IQS must have at its command a comprehensive set of active data exchange links so that it is able to gather data from all other data holding systems within the organisation. Furthermore, the operation of such links must be driven entirely by the IQS since modifications to existing software can be neither expected nor demanded. This issue is further complicated by the enormous range of products which are in use in industry, any of which may be called upon to supply data to the IQS. However, the emergence of standards such as STEP and EXPRESS, supported by NEUTRABAS, PROFIBUS and FIP, will greatly aid the development of the necessary interfaces.

12.3.2 Customisation

In order to develop a generic IQS a number of matters must be considered because no two organisations are the same. Thus each IQS must be customised to fit a unique niche in the organisation. Every installation will be different, with variations in procedures,

working practices, processes and product or service, and in the information systems already in place. This creates significant problems in the development of a truly commercial implementation of the IQS concept.

The impact of varying procedures and working practices on the IQS will be minimal and largely limited to the design of a set of company specific reports. Variations in processes and products are much more significant because these are the primary focus of any quality system. The IQS concept should be applicable to all types of industry, whether it be discrete parts or continuous process manufacture or even the provision of services, since the main differences between these activities concern the criteria and methods employed to judge their quality.

Of much more significance will be variations in the levels of computerisation and available CIM sub-systems between organisations. The exact IT profile of each company will determine the configuration of the IQS, specifically which interfaces must be provided, what quality services must be offered by the IQS and what data will reside in the local IQS knowledge base.

Thus it can be seen that full generalisation of the IQS will require major development resources to cover the vast range of interfaces which should be offered, however, the task is not inherently complex, only very large. In particular, it should be noted that the proposed structure does not require that the linked systems must be RDBMS's accessed using SQL. The structure proposed for the generic IQS is flexible and will

allow incremental implementation, so that the system could be initially installed with limited functionality and data resources, and then gradually enhanced as new interfaces are added and more data becomes accessible.

12.3.3 Yellow Pages Initialization

In order for the IQS to access data held in another system, it is necessary that a Yellow Pages listing for that data exists. Thus, at system set up time, the Yellow Pages must be loaded with references for all data held by other systems in the organisation. Clearly this is a major task as it entails the preparation of a full data dictionary for the organisation. In practice, it is evident that requiring that the Yellow Pages be fully loaded before becoming operational would impose a lengthy and unacceptable delay in the installation of an IQS. Therefore, the Yellow Pages should be loaded incrementally. Hence, the IQS can be brought into use more rapidly. Even though the IQS will be operating only on a partial data set, worthwhile benefits will still be provided, and these will increase in proportion to the completeness of the Yellow Pages listing. Furthermore, this initialization strategy would be well suited to the modification of the IQS later in operational life, when it may be necessary of add new links and interfaces as the profile of information systems within the organisation evolves. It should also be noted that this evolution may result in the demise of a given system, thus requiring editing of the Yellow Pages listing.

12.3.4 Initiative

It is the judgement of this author that database techniques alone are insufficient as a means of implementing a true IQS to operate in a Total Quality environment. This is because in some circumstances there is a need for the IQS to have the ability not only to analyse situations, but then to review sets of predefined responsive actions and select and initiate the most appropriate; all without human intervention. This level of system initiative cannot be achieved by a pure database, but could be provided by Artificial Intelligence (AI) mechanisms such as Expert systems or possibly Neural Nets. Conversely, although they would be able to provide the level of initiative for needed by the IQS, such AI mechanisms are not able to match the data handling capabilities of true databases. Since the IQS requires both comprehensive data storage and querying functionality and initiative, it must be implemented by means of so called "Knowledge-based" techniques; that is by using a hybrid which combines a traditional database with an AI system. Several such systems are described in Butler et al [11], Kennedy and Crerar [69], and Kinoshita et al [72].

12.4 Other Application Areas

The concept of the Total Quality Database as an integration mechanism has wider application than just within manufacturing operations. This idea is now being applied to the production and transportation of Citrus Fruit with the remit of a collaborative project funded under the European Commission's ESPRIT II research initiative. The goal of this project is product life tracking for fruit in transit with a view to the

provision of information on how changes in the conditions experienced by the fruit during transportation effect the quality of individual shipments of fruit. This will be achieved be the development of a cheap, re-useable sensing device which will travel with the fruit. Data collected by this device during the journey will be combined with data concerning both pre and post harvest conditions and treatments, and known characteristics of the relevant fruit variety. Analysis will then provide information concerning the aging of the fruit in the shipment and whether there is evidence to suggest that the fruit has been damaged, either physically or by disease. The results of this analysis will be of use to both the wholesaler and retailer and, in the longer term, might be used to provide the final customer with a detailed history of the fruit which they are purchasing.

The main thrust of the work is the development of the sensing device, which will comprise an array of sensors of different types, supported by analysis software so that readings can be correlated to determine, for example, the type of disease which is affecting a damaged fruit. However, the analysis relies on knowledge about the life history of the fruit. It has therefore been necessary to design a distributed database so that data from all parts of the fruit life cycle can be conveniently collected and integrated within the total system. Figure 12.1 presents the likely schematic for this system. The FRUIT architecture may also be applied to a variety of other food products, be they fruit, vegetable, dairy, meat or fish.

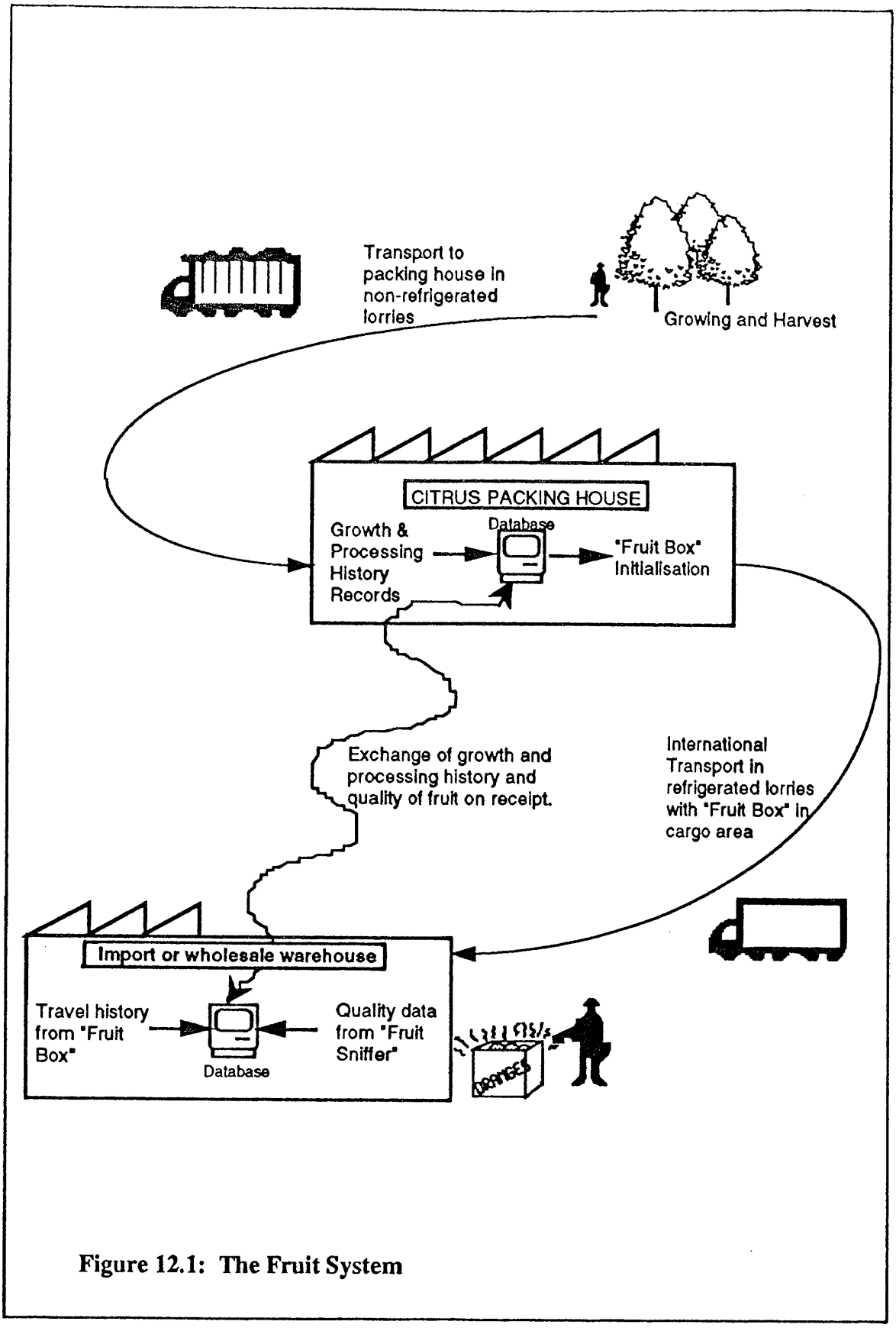


Figure 12.1: The Fruit System

Further details of this application and the solutions proposed are given in Knight et al [73] and also in the deliverables associated with the project, ESPRIT project number 5379 - FRUIT [35]. The project team is lead by The University of the West of England, Bristol (this author is the Project Coordinator) in partnership with Fomesa (Food Machinery Española), Robotec Ltd, Syntax Factory Automation and Trademco Ltd. The project commenced on 15th October 1990 and is expected to complete in April 1993.

12.5 Related Work

A number of projects in related areas have recently been funded by the European Commission. All of these projects are cross-Europe collaborations with significant industrial involvement.

12.5.1 ESPRIT RA-IQSE

Esprit project 2178, "Revision Advisor - an Integrated Quality Support Environment" (RA-IQSE) [34] was concerned with the provision of a system to aid the optimisation of products manufactured in highly automated production facilities. The work of RA-IQSE focused particularly on design and production planning phases of manufacture. The underlying hypothesis of the project is that the quality of a given product can be predicted by analysis during the design stage, and that any necessary modifications can then be introduced immediately so as to minimise the effects (in particular in terms of

cost) of a foreseen quality failure. While this hypothesis is widely accepted, it is rarely applied in practice because of the general lack of availability of information to designers at the appropriate time (ie. prior to the commencement of production).

Irgens [57] describes the way the system supports the design process. First, where a variant design is required, a search is carried out to establish a link between the new specification and ones held in the historical database. The user may specify matching criteria and priorities. Second, a check is made to detect any inconsistencies in the requirements specification. This includes the identification and description of any conflicts and assures the satisfaction of the functional requirements. Third, a quality evaluation is carried out. This assesses both the manufacturability of the product against the known capabilities of the organisation, and evaluates the product's performance against predefined metrics, judged in the light of quality observation data. This performance analysis utilises some specially developed techniques for assigning numeric measures to quality observations; further details are given in MacArthur [84]. Finally, quality advice is given to the user. This is available through two functions; diagnosis which interprets the quality evaluations, and repair which proposes possible ways of correcting identified failures.

The work of RA-IQSE provides the basis for one of the most important core modules of the IQS in its support for design and production planning. This is one of the key areas in assuring the quality of the finished product. It is also surely one of the most complex processes for which to provide computer support. This is for two main

reasons. Firstly, the design process is highly intuitive and therefore any support tools must operate in such a way that they do not interfere with the designer's natural mode of work. Secondly, in order to provide advice the IQSE must be able to recognise features or parts and then find any items in the quality history database which may be relevant in judging the quality of that feature or part. This requires a complex coding system in the historical data, with provision for a single item of data to have multiple identification tags where it may be relevant to several features or parts.

12.5.2 ESPRIT NEUTRABAS

Esprit project 2010, "Neutral Product Definition Database for Large Multi-functional Systems" (NEUTRABAS) was concerned with the development of a neutral product definition database for large and complex systems such as ships. This neutrality has been achieved by the use of a pair of developing ISO standards, STEP and EXPRESS, for information modelling, combined with a standardised maritime product information model developed within the NEUTRABAS project. However, neutrality alone is not sufficient, it is also necessary for the database to be both complete and flexible in access, containing all data relevant to all product functions at all pertinent stages in the product's life cycle. This data must have the ability to be viewed from a variety of different functional focuses and be suitable for decomposition and distribution in an open systems environment. The achievement of these criteria leads to improved communications between the enterprises involved in the development, manufacture and use of the system, better integration throughout the CIM cycle, improved activity

management under concurrent engineering, and easier collaboration with other industries as a result of better and more open software links. The project is described by Fernadez-Gonzalez et al [39].

Although NEUTRABAS has not directly attempted to address the problem of data provision for quality assurance, the neutral product definition database would very much simplify the integration problems which must be tackled in the implementation of the IQS in order to give the CQDB access, via its Yellow Pages directory, to such quality relevant data as is held throughout the CIM system.

12.5.3 EUREKA QMIS

In the summer of 1990, the industrial relevance of this work was recognised when the Department of Trade and Industry funded a consortium of leading workers from academia (including this author) and manufacturing computer systems houses to carry out a feasibility study in preparation for a collaborative project to develop a commercial implementation of the Quality Management Information system described herein. Following this feasibility study, a larger project was funded to develop further methods of integrating quality into the functions of product design and process planning. Purslow and Tannock [108] have presented some of the early results of the project, including a prototype knowledge based quality planning system which works with a computer aided feature definition technique.

While of some interest in relation to the IQS, the results of this project are somewhat disappointing as they address much the same area as RA-IQSE but in a much more simplistic manner. Even so it may be that some of the prototypes developed could be of use in an IQS for use in an organisation with a fairly simple product design which does not require the power of the RA-IQSE approach, however, this appears doubtful.

12.5.4 PROFIBUS and FIP

In their paper, Pfeifer and Stölben [106] examine the need for adequate networking to link the lower levels of production-integrated quality management. They highlight in particular the problems for data exchange between sensors, actuators, coordinate measuring machines and other measuring equipment in the context of computer integrated production and assembly. Difficulties often arise because of a lack of standardisation in communications at the field level. PROFIBUS (Process Field Bus) and FIP (Factory Instrumentation Protocol) are two proposals for national standards relating to field level open communications. They are being prepared by Germany and France respectively, and are expected to form the basis for first a US draft standard and subsequently an international standard.

With relation to the IQS, this work is clearly of great importance since a quality system without true data automation of the inspection activity fails in its main purpose; that of providing timely information to support process monitoring and improvement. The work undertaken in the ACME project on which this author was employed

demonstrated the difficulties of linking automatic measuring devices manufactured by different companies. The solution used was the development of special interfaces between the QDAAS and the devices working under its control (Wort [149]). However, this approach would not be feasible for an installation with a wide variety of devices to be linked. Thus the work on PROFIBUS and FIP is vital to the eventual development of a true IQS to suit an organisation.

12.6 Further Work

There is now evidence that the European Commission perceives quality to be of importance in improving the competitive position of European companies in the world market. An initiative in the computer aided quality arena was launched by the European Commission in the October 1991 ESPRIT III call, with a view to new projects starting in the third quarter of 1992. A number of proposals were submitted in this area and, following the evaluation process, two were funded. Project 6559 (UNIQUE) plans to apply a knowledge-based approach to quality control to provide a unified quality environment, while project 6572 (ITAQUA) plans to improve quality management in small and medium sized enterprises by promoting a set of methods and procedures complemented by easy-to-use software tools. Neither of these projects proposes a fully integrated environment for quality support as suggested herein, but both represent significant moves towards the eventual realisation of a true IQS. Also of interest is the recent BRITE/EURAM call which highlighted the need for methods of quality improvement throughout the production process.

It is the view of this author that there is a need for further investigation into the modelling of quality information system already extant in organisations. The ACME funded project from which this work arose studied only one site of a large, multi-divisional, international manufacturing organisation. The picture thus formed can only be a partial representation of reality. Therefore, to gain a more informed view, it is necessary to undertake similar studies; firstly, in the same market sector so as to ensure that the original site was typical of that sector; secondly, in other market sectors to ascertain variations between sectors; and thirdly, across different countries to assess the effects of variations in working practices, social organisation, legislation or customer requirements.

Clearly, the achievement of such a study is a mammoth undertaking, requiring many years of effort, however, it is not necessary to await the final report before taking action. The original Du Pont study has proved to be very valuable as a breeding ground for ideas on the computerisation of quality information systems. These ideas have, so far, been tested only against this one site and against such reports as are to be found in the literature, but this has already provided guidance for the evolution of the original concept. Furthermore, discussions with workers from the RA-IQSE and QMIS projects, and with consortium members during the development of the MARQUIS and LEQUIC proposals have resulted in strong expressions of interest in the IQS concept, combined with a willingness on the part of industrial representatives to provide significant resources for future collaborative work with a view to developing a full industrial implementation of the IQS. It is worth noting that the industrial interest takes two

distinct forms; firstly, manufacturing organisations who feel that such a system would improve their competitive edge, and secondly, software houses who perceive in the IQS a valuable future product line.

12.7 Conclusions

At the outset of this study, it was proposed that the needs of a quality control system in a company could be satisfied by the provision of a database holding primarily data relating to inspection specifications and procedures and historical records of inspection results. However, the findings of a literature survey combined with the wishes expressed by staff at the test site during the development of the Desiderata made it clear that this was not the case. Firstly, that the achievement of quality control was not adequate for the maintenance of competitive position in the current climate; the preferred goal should be Total Quality Management. Secondly, that, as a result, a far wider data set was desirable as a base for focused decision making. Thirdly, that there were additional quality specific functions which could usefully be provided to supplement inspection control and recording. Thus the requirement was modified to a database able to supply data concerning all organisational activities and having functionality sufficient to support a number of quality specific tasks.

Initially, the idea of a quality database which held all quality related data seemed attractive. However, considering the range of organisational activities identified under TQM and the resultant scope and quantity of data that could thus be considered to be

quality related, a number of weaknesses were identified. In itself the size of the quality database was not a problem, but the high proportion of the data which was already held in other information systems within the organisation was. This would give rise to significant levels of data duplication, and thus to problems in maintaining the consistency and currency of the data. Since much of the data would be transferred to the quality database from other systems which were the primary data users and owners, it is likely that the quality database would lag behind, never being quite up-to-date or reliably reflecting changes in previously transferred data. Furthermore, there would be a significant overhead associated with the transfer of data into the quality database which would militate against all requisite data being included. Therefore, the use of a monolithic database for quality is not an appropriate solution. In addition, it became clear that the role of a computer system for supporting TQM should not be the collection of an ever-widening set of data, but instead that it should provide better access to existing data thus enhancing the cost effectiveness of the data held.

The IQS prototype described herein explores the first steps towards an alternate solution which avoids the need for major data transfer and thus eliminates the consistency maintenance problem. Of course, the prototype does not provide a full solution to the problem of flexibly accessing and integrating data across the entire organisation, but it has been useful as a testbed for the underlying concept and clearly points the way to an appropriate generic architecture which would achieve these goals. The proposed structure provides a good deal of flexibility in that it could be implemented incrementally and used at several levels, from quality control, through quality assurance

and on up to full support of TQM. Generation, storage and maintenance of documentation required by standards such as ISO 9000 will be facilitated, and specific techniques, such as SPC, may be easily incorporated by linking specialist commercial software to the core IQS in exactly the same way as other CIM sub-systems. With regard to the support of activities early in the product life cycle, several point are of interest. Firstly, many design activities, whether concerned with the product or the production process, could accrue benefits from the easy, flexible access to historical data made possible by the IQS. This would apply whether or not special techniques, such as FMEA or Quality Function Deployment, were utilised during the design process. Secondly, the IQS architecture would permit the integration of powerful design support tools, such as the RA-IQSE system, thus providing them with a very much larger set of base data on which to work.

This study has not concerned itself with the development of systems to directly implement individual quality techniques (such as Taguchi, SPC or Quality Circles), but rather has taken the view that all techniques rely, in varying degree, on the availability of quality data. Therefore, it is incumbent on the quality information system to make the requisite data easily accessible to every actor in the quality system so that the best use can be made of this valuable resource. Furthermore, it has been recognised that significant quantities of what might be viewed as quality data are already held by other information systems in any manufacturing organisation. Thus it falls to the IQS to provide an access mechanism for this data, so that users are not required to know which information system holds the data they need, but only that they can specify functionally

those items which must be included in a given query or report.

The obvious solution for the provision of this service is that the IQS should hold duplicate copies of all quality data, however, this is not an acceptable solution for the following reasons. Firstly, standard database theory clearly states that data duplication is undesirable because of the problems associated with the maintenance of consistency between copies. Secondly, the amount of data involved is extremely large, thus the provision of many additional mass storage devices would be required to accommodate the duplicated data. These requirements would be magnified by the need to maintain backups of this important data, in addition to those kept for other systems throughout the organisation. Thus, it can be seen that at least four copies of the quality data would be held, possibly more, depending on the backup strategy employed by the company. This is undesirable in both financial terms, ie. cost of hardware, storage media and staffing, and also because, in many organisations, there would be problems in justifying the necessary floor space to accommodate the storage media.

Hence, it is proposed that the IQS hold only such data as is not stored elsewhere, and that, for all other data, it should maintain a type of "Yellow Pages" directory which identifies data functionally and gives its location in the organisational information system structure. Thus it can be seen that the IQS will have a central role in the monitoring of the structure of the CIM operations across the entire organisation. This leads to a situation where the IQS may be seen as the superior data server in the organisation, in that it might be used to facilitate inter-system data exchange required

for purposes other than quality management. Therefore, the development of a true IQS in an organisation will not only provide active support for TQM, but will provide the mechanism for the management of all data extant in the various modules of a CIM installation.

Appendix 1

Quality Support Software

A1.1 Introduction

A wide variety of what could be called "Quality Support Systems" are already in existence. A cursery inspection will often suggest that a given system provides the same functionality as is proposed for the full IQS described in this thesis. Deeper investigation, however, reveals that the majority are limited to study of events on the production line, frequently with product design falling outside the system boundaries. Some systems purport to address the documentation requirements set forth in BS 5750, whilst others focus on computerising SPC. Each has some significant quality relevant feature, but none provides either the full range of functionality envisaged for the IQS, or achieves the level of data integration necessary to make the best use of all data which has been collected by the orgainsation.

A small selection of these systems are discussed in this appendix; the information presented being drawn from several sources; product sales documents, demonstrations, technical publications and papers, demonstrations. The systems described fall into two groups; firstly, those which are commercial software products, and secondly, those developed in-house to satisfy the needs of a particular company. It is not intended that this appendix should cover all, or even a significant number, of available quality support products, but only that the examples discussed may give a feel for the scope of products on the market.

A1.2 QDM - Quality Decision Management/1000

Hewlett Packard

The first was developed at the Hewlett Packard Disc Memory Division (DMD) in Boise, Idaho, USA. Hewlett Packard [53] describe how, in the early 1980's, DMD established the need for Statistical Process Monitoring of the disc media module manufacturing process, which, at that time, was yielding only about 30%. Manual statistical analysis was not feasible because over 400 data items had to be gathered for each module built. Thus, not only did manual data acquisition take far too long, but the correlation, analysis and result presentation necessary to gain value from the data once gathered was too complex to be done manually. This was in direct contradiction with the need for the rapid identification of non conformance and determination of the reason for the undesirable process variation with as short a delay as possible to minimise the production of further non conformant modules. The situation was further complicated by the complexity of the manufacturing process, where multiplicative yield effects tended to produce low yields. Thus it was desirable to gain a better understanding of the process so that it could be simplified.

Being unable to find an "off-the-shelf" quality management system with the power and flexibility to satisfy their needs, DMD wrote a quality and test management software package specifically for their disc memory media module assembly area. Subsequently, with this package as a base, Hewlett Packard R&D created the application solution product "HP Quality Decision Management/1000", a tool for quality management which allowed DMD to meet their major goal of substantially increasing yields as a direct

result of the improved information feedback provided by the new system. Further gains were achieved due to the significant simplification of the production process. The direct benefits achieved one year after implementation are quoted as an improvement in yield from 30% to 70%, with 700 fewer failed media modules being manufactured each month; production levels are now more even in contrast to the fluctuations which used to occur at different times on the month; more accurate knowledge of vendor quality levels is available, thus allowing elimination of poor vendors, and collaboration with the better vendors to evaluate and upgrade their quality levels. A number of indirect benefits have also been realised, such as a shortening of the overall cycle time as a result of the simplification of the manufacturing process; lower inventory because of the proven predictability of the higher yields being achieved; higher employee morale has resulted because easy access to accurate and timely data has improved decision making and consequently reduced levels of errors and frustration, in addition, there have been major reductions in the time taken to investigate and fix process problems because of the improved data availability; significant reductions in rework has allowed better use of resources, thus providing greater production capacity in the available floor space.

QDM was designed to run on the Hewlett Packard 1000 mini-computer. After the success at DMD, it was subsequently commercialised in 1983, although in recent years, with the replacement of the HP 1000 platform by newer architectures, the QDM software is no longer available. This product has been reviewed by Cullen [24].

QDM collects and analyses multi-variate test data to provide rapid feedback on the production process and vendor quality levels. It produces both statistical information (in the form of histograms, scattergrams and control charts) and a wide variety of reports and graphs. This increases understanding of the manufacturing process which may then lead to modifications of that process, however, it is not used to support the design of new products nor the processes necessary to make them. Thus it is not an integrated quality system as defined in this thesis because it is only concerned with product quality as influenced by vendor quality and the production process; it does not take the wider view required under TQM.

A1.3 Production Line Data Collection & Unit Tracking System

G Stiles, Hewlett Packard

This system was developed by G Stiles [123] in 1989 for use at the Computer Peripherals bristol division of Hewlett Packard during the industrial project phase of an MSc in Information Engineering. It was introduced to cope with a variety of similar products being build on a single production line, and was require to ensure that each variant passed through the correct processing steps and underwent the appropriate tests.

Orders are set up manually through the keyboard to provide guidance for the line's operators on what to build. Build and test sequences are defined in the form of a program or sequence file held in the system's database. Where process changes take place, it is necessary to ensure that the operators are cognisant with them, thus the

system incorporates an operator accreditation scheme, so that the line supervisor can advise the database which operators have been trained to carry our each process. This is checked as each operator logs in, and only those correctly accredited are permitted to undertake a given process.

The primary purpose of the system is tracking what has been done to a particular unit, when and by whom, how long the operation took and finally, the results of any required tests, including, where appropriate, details of failure. This last data set being part of a failure analysis record generated each time a unit failed a process to allow determination of the root cause of failure.

As has been mentioned in chapter 9, this system is not, as it stands, either a viable or a complete quality information system. It is, however, a necessary component of the comprehensive IQS described herein.

A1.4 Rexword Automation Inc

In his paper, Faillace [36] describes very briefly a Quality Assurance database in use as part of a TQA programme at RAI. It includes data on production quality, incoming material quality, calibrative control and vendor analysis. The system runs on a stand-alone microcomputer using the dBASE III RDBMS to store the data and provide a menu-driven user interface and a set of standard reports. Data entry is done by the QA departmental secretary. A second database is held by the ? support group for analysing

repairs and field failure data and tracking repair job orders. An additional module is planned for tracking the manufacturing of spares ordered by customers.

This system provides a number of the functionalities required for in a QIS but has certain weaknesses. Firstly, the use of stand-alone micro as a platform combined with QA taking responsibility for data entry, isolates the data from its true owners, those on the production line, and thus also removes ownership of problems and initiative for improvement. Instead ownership is taken by the QA department, in direct contravention of the Total Quality ideal.

Secondly, although it is already giving rise to benefits, the use of separate micros in this solution will tend to increase data duplication and fragmentation across the company by introducing a new "island of information". Furthermore, no mention is made of data exchange between the 2 modes, nor with any other system in the company. Finally, it is unlikely that a micro of the type stated would have the capacity necessary to support a large installation for more than a few months.

In addition, Faillace presents arguments for the selection of a RDBMS rather than a Hierarchical database and then outlines the steps to be followed to develop a database using an RDBMS. Whilst it is nice to see support for the use of RDBMS' for quality databases, it is unfortunate that Faillace betrays a lack of knowledge of the subject in a number of significant areas. It is also somewhat worrying that the simplicity of the development procedure presented suggests that the design and implementation of a

database is an easy task which can be carried out by any interested amateur without professional help. In the view of this author, the encouragement of this idea is most dangerous as is likely to lead to much unnecessary expense in respect of staff time for system development, data entry and subsequently trying to alter the system when it is found not to achieve the required tasks. This will cause much frustration. Finally, it is likely that professionals will be called in to sort out the mess, resulting of course in further cost. At this stage, the original system developer will be very loath to allow the professional to start again from scratch, rather than modifying the existing unsuitable system, but this latter option is very much the more expensive and will normally yield a inferior finished system.

A1.5 Quality Records Management System (QRMS)

Rede Products Ltd

QRMS is designed to address the problem of managing and making accessible the wide variety of records required by BS 5750 and ISO 9000. It has eight modules; these being:

Calibration Management

Change Control Management

Non-Conformance Management

Quality Systems Audit Management

Quality Cost Management

Supplier Management

Training Records Management

Documentation Management.

Together, these modules quite comprehensively cover the needs of a QA system, whether or not it conforms to BS 5750. The producers of QRMS have recognised that most companies have a wealth of untapped knowledge trapped in their data archive rooms, held either on paper or microfiche. Typically, the data has been collected and tabulated, at some expense, only because BS 5750 requires it. Thereafter, no further benefits are gained from it, principally because of the difficulty of access. QRMS allows such records to be reused and analysed, thus bringing to light improvement opportunities which may lead, not only to improved quality, but also normally to cost savings.

QRMS seems to match up well to the requirements set out for the IQS. Even though it is PC based, the inadequacy of a single station quality records system has been recognised and a multi-user application is available. This supports networks such as Novell and 3COMM. QRMS will also run on microcomputers or mainframes which allow DOS applications to run in a multi-user environment. The main criticism of QRMS is that its introduction will have the effect of segregating so-called quality records from other information available in the company, thus precluding the likely benefits of full data integration. In addition, there may be some danger of the system becoming solely the balywick of the Quality department because only they will tend to use it with sufficient frequency to achieve familiarity and confidence in its use. Even

so, Moore [90] reports that the introduction of QRMS at Anglian Windows has greatly enhanced control of the quality system because it has made possible the achievement of commonality in inspection methods and has made the company's position stronger when dealing with suppliers because it provides more effective integration of quality management functions and aids rapid updating of information.

A1.6 SPC+ Statistical Process Control System

General Automation Ltd, Gerrards Cross, Coventry, Birmingham and Coatbridge

SPC+ can handle both variable and attribute data and supports flexible data formats. Data entry can be either manual or via General Automation's networked data capture terminals. In addition, automatic data capture can be achieved by linking gauging or measurement devices, or process central computers to the SPC+ system. Incoming data is processed in real-time so that out of control situations detected are notified to the user immediately.

SPC+ provides only a very limited sub-set of the wide range of available charts; for variable data the user can select mean, range or standard deviation, while for attributes only percentage defective is provided. Although these are the most commonly used charts, this lack of choice, particularly for analysis of attribute data, is undesirably restrictive. Furthermore, from SPC+'s sales literature it is clear that mean, range and standard deviation are completely separate options and pairs of plots cannot be displayed together, despite the fact that combined mean and range or mean and standard

deviation charts are standard because the combination is considerably more informative than any of the three used separately.

SPC+ has a facility for calculation of control limits, but does not use the widely accepted combinations of warning and action limits. However, in a strict sense the rules used to recognise an out of control situation are correct.

SPC+ is implemented on General Automation's own Zebra computer which runs under the Pick operating system. This choice of hardware and OS may cause problems in the integration of SPC+ with other products across an organisation.

A1.7 QAD - Quality Assurance Database

Reliability Consultants Ltd, Fareham, Hampshire.

QAD was developed using SSADM in accordance with quality procedures approved under the NATO standards AQAP 1(3) and AQAP 13 (AQAP stands for Allied Quality Assurance Procedures). It was originally developed for the European Space Agency. It is built around the Oracle RDBMS and is therefore portable across all hardware platforms supported by Oracle. The minimum configuration is an IBM PC AT (or true compatible) with 1 Mbyte of extended memory. The cost for a single user IBM PC installation is £5,800, plus an annual support fee of £870. Costs for installations on other hardware are largely dependent on Oracle software prices which vary according to the model of computer in question. This is significant because QAD contains a full

runtime version of Oracle, which must therefore be purchased as an integral part of the product. Multi-user versions of the QAD software are licensed at £5,800 plus £1,250 per user, plus the cost of Oracle on the desired hardware. (All prices quoted are as at March 1989).

A1.8 Quality Monitor

Information Management Ltd, Bristol.

Quality Monitor is an IBM PC based system capable of running either as a stand-alone or networked system. It provides full change control of test procedures and product specifications, and time-stamps all test results to achieve full audiability and traceability. It provides integral SPC functionality with a quite wide range of control charts. It has extensive reporting facilities, with the ability to customise standard reports and export data to proprietary spreadsheet and graphics packages. In addition to these functions, there are suggestions is some of the publicity material that integration with other "control systems" is possible, however, the User Guide makes no mention of this at all.

This product provides comprehensive coverage for quality control of production but really only pays lip service to the wider needs of TQM, although the flexible reports available would permit some support of quality assurance activities in design.

Appendix 2

Database Management Systems and Other Software Tools.

A2.1 Underlying database structures

At present three models are used to structure data held in databases, these are known as the Hierarchical, Network and Relational models. A fourth model, the Object Oriented database, has existed in theory for some while, but has only recently been fully implemented as a commercial product. Each model has its own set of advantages and disadvantages; it is therefore necessary to consider carefully the suitability of each structure for a particular task. This appendix gives only a very brief overview of the differences between model; for more detailed information, readers are referred to the short database bibliography given in section A2.3.

A2.1.1 The Hierarchical Model

Data is represented by means of a collection of simple tree structures, such that sets of data are subordinated to an individual master data record. For example, consider a database composed of information about parts, and the suppliers of those parts. Using the hierarchical model, there are two possible ways of structuring this data. Either each part record has dependent upon it records for all suppliers of that part, or each supplier has subordinate records for all the parts which it supplies. In both scenarios several problems may occur.

1. Duplication of subordinate data records may occur where a given record is related to more than one superior record. This leads to difficulties in maintaining data consistency.

2. Lack of symmetry in the retrieval of data to satisfy apparently symmetrical queries.

3. Lack of data independence because subordinate records can only exist if there is a master record on which they can depend. This may cause problems in both insert and delete operations. Furthermore, subordinate data may be lost if the master record is deleted.

The main advantage of this model is that it is the natural way of handling truly hierarchical structures from the real world, although symmetry problems may still occur. Also, because of its simplicity, it may be useful for constructing small databases.

A2.1.2 The Network Model

The Network model uses intermediate linking records to connect dependent records within the database, thus allowing the representation of many to many relationships between the various types of record required in the schema. This structure solves the data duplication problem found in the Hierarchical model. The Network approach solves the problem of retrieval symmetry, however, its data accessing procedures are

rather more complex.

Inconsistency as a result of insertion, deletion or updating of data records cannot occur because there is no data duplication. But, these functions carry a significant overhead as they require a high degree of additional operational complexity because of the house-keeping necessary to maintain the link chains within the database.

On the negative side, it must be realised that the Network approach, like the Hierarchical, does not achieve data independence. Also that, even in the case of a very small, simple database, large overheads are introduced by the complex natures of both the data model and the data sublanguage required to manipulate it, this complexity being a direct result of increases in the range of information bearing constructs supported in the data model.

A2.1.3 The Relational Model

Following the establishment of the "Company database" (using either Hierarchical or Network database management systems) as a standard and essential piece of corporate software, the theory of the Relational model was developed by E F Codd. In the Relational model all information is represented in a uniform manner, namely, in the form of flat tables. This uniformity gives rise to several advantages:

1. The data sublanguage employed for manipulation of the database is simple.

2. Symmetrical queries of the database are satisfied by symmetrical retrieval routines.

3. Data independence is achieved.

4. Insertion, deletion and updating are simple, although precautions must be taken to ensure that consistency is maintained throughout the database where data items are duplicated across tables.

For several years, despite the theoretical superiority of the Relational model, few commercial databases employed it. The main reason for this lack of interest was the inability of practical implementations the Relational model to match the performances achieved by databases based on the Network and Hierarchical models. This problem has now been overcome, with the result that Relational database management systems are now widely available, with many implementations being provided for PCs. Although, no presently available RDBMS completely conforms to the rules set out by Codd, these packages have gained increasing popularity. The principal reason for this is the high standard to the user interfaces provided, which is such that many RDBMS are very easy for the novice to learn. In some cases, this ease of use is combined with powerful tools and a high degree of conformity to Codd's Rules. Thus the Relational model has been widely adopted both to support highly complex, large, often company-wide databases, but also for use in supporting day to day office record keeping activities.

Another factor which must be consider to be an advantage, is the existence of an International Standard language for Relational databases; SQL (Structured Query Language). While SQL is not universally implemented as part of commercial RDBMS products, it has a sufficiently wide coverage to provide a reasonable level of portability between different RDBMS packages.

A2.1.4 The Object Oriented Database

The concept of the Object Oriented database stems from the rules which govern object oriented programming languages; thus it is a collection of objects whose behaviour, and the relationships between objects, are defined in accordance with an object oriented data model. In theory, the OODB presents several advantages over the traditional relational database model because it attempts to provide solutions for several of the limitations inherent in the Relational model. For example, provision of complex nested data objects, the ability to store and retrieve arbitrarily long data item such as free text, extension of the available data type to allow definition and manipulation of user defined types, version control. However, the successful implementation of these concepts has proved difficult and so the emergence of OODBs into the marketplace has been slow.

At commencement of this work, there were no commercial implementations of object oriented databases which fully achieved both the theoretical concept, and provided the full range of facilities, coupled with simplicity of use, provided by modern Relational systems. However, since that time, a number of organisations have been undertaking

serious research and development work so that there are now a number of commercial OODBs on the market.

A2.2 Recommendation for Database Model to be used in the prototype IQS.

It is proposed that the Relational model be used for the development of the prototype IQS. This model is the most flexible in terms of schema design, whilst the majority of commercial RDBMS provide extremely good rapid development interfaces, which will facilitate evolutionary prototyping. Furthermore, the large selection of commercial packages of the market will allow good coverage of possible hardware platforms. Ideally, the chosen package should provide SQL, thus giving an underlying standard to permit code porting between different RDBMS products.

It is deemed possible however that, in the next few years Object Oriented database technology will mature significantly. It is therefore recommended that OODBs should be reconsidered prior to implementation of the commercial IQS.

A2.3 Database Bibliography

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Addison-Wesley, ISBN 0-201-41604-2, 1990

Appendix 3

The Flunkeys

Detailed Functional Specification of Active Element Tasks

A3.1 Introduction.

In order to illustrate the interaction between flunkeys the following sections (A3.2 - A3.6) present detailed functional specifications for some of the Active Element tasks identified in chapter 10.

A3.2 Down-loading of inspection specifications for all planned work orders for the forthcoming production period from the CQDB to the QDAAS.

a) At the start of a production period, each QDAAS starts up and notifies the "Butler" that it is active and awaiting inspection specifications.

b) The "Butler" inserts a record into noticeboard table requesting inspection specifications for current production period to be prepared for a named QDAAS.

c) The "Housekeeper" finds request in noticeboard table and activates a "Footman".

d) The "Footman" selects inspection specifications by reference to the production schedule and prepares a file for collection by the "Butler".

e) The "Footman" modifies the pertinent record in noticeboard table to show specifications ready for collection.

f) The "Butler" checks noticeboard table and collects any waiting specification files and delivers them to the requesting QDAAS.

g) The "Butler" modifies the noticeboard table record to show that the requested specifications have been collected.

h) From the noticeboard table, the "Housekeeper" determines which prepared specification files have been collected and instructs the "Cleaner" to delete them, and also remove the appropriate record from the noticeboard table.

A3.3 Down-loading of single inspection specs in response to a request to the CQDB from a QDAAS for a specification to govern the inspection of a particular work order.

a) QDAAS user indicates need for an inspection specification currently not down-loaded.

b) QDAAS requests user to enter the required work order number.

c) QDAAS requests "Butler" to obtain an inspection specification for the given

work order number and inspection station type.

d) The "Butler" places request in noticeboard table.

Thereafter, procedure as per c - h of A3.2 above, except that in d the stated work order number will be used instead of the production schedule for control of inspection specification selection.

A3.4 Up-loading of batch summary reports to the CQDB when a QDAAS encounters an end of batch followed by automatic generation of certificates of conformance (COCs) for completed batch.

a) At end of batch, QDAAS prepares batch summary and requests the "Butler" to transfer it to the CQDB.

b) "Butler" delivers data from QDAAS into temporary tables within the CQDB and creates record in noticeboard table to show that a delivery has been made.

c) On finding a delivery note in noticeboard table, the "Housekeeper" activates a "Porter" to transfer batch summary from the temporary tables into the master tables in the CQDB. The "Porter" requests the "Cleaner" to clear the temporary tables, then modifies noticeboard table record to acknowledge assimilation of the data into the master tables. If data cannot be transferred for some reason (eg.

corruption), "Porter" modifies noticeboard table to request the "Butler" to retransmit the data, and tells the "Cleaner" to clear temporary tables.

d) The "Butler" checks the noticeboard table and either retransmits data (ie. repeat actions from a), or notifies the QDAAS that the summary has been assimilated into the CQDB and deletes the assimilation acknowledgement from the noticeboard table.

e) The "Housekeeper" activates a "Clerk" to check whether all required inspections for that work order have been completed. If so the "Clerk" generates a COC for the batch, otherwise no further action is taken. Where a batch fails some required inspection, a corrective action request is issued.

f) The QDAAS may delete its copy of the batch summary once it receives notification of successful data assimilation.

A3.5 Up-loading of an interim batch summary report about a continuing batch from a QDAAS, at the request of the CQDB.

a) The CQDB places a record in noticeboard table requesting an interim batch summary for a stated work order.

b) The "Butler" finds request & notifies the relevant QDAAS. This may involve

more than one QDAAS where multiple inspection activities are called for in the specification.

c) The "Butler" notifies the CQDB of the number of QDAAS which are expected to supply the requested interim reports.

d) The QDAAS prepares interim summary and notifies "Butler" when it is ready for transfer.

e) The "Butler" delivers the data from the QDAAS into temporary tables in the CQDB and modifies the record in the noticeboard table to show that the delivery has been made.

f) On finding a delivery note in noticeboard table, the "Housekeeper" activates the "Reporter" to check whether all expected reports have been received, and if so to create required report from the temporary tables. The "Housekeeper" then modifies the noticeboard table to acknowledge receipt.

g) The "Housekeeper" orders the "Cleaner" to clear the temporary tables. In case of bad transmission, Housekeeper resets noticeboard table to request retransmission (as per a).

h) The "Butler" finds acknowledgment of receipt.

A3.6 Activating time-dependent activities within the CQDB (eg. regular reports).

a) The "Timekeeper" checks the Diary table, which contains a list of activation times for periodic activities, against the current date.

b) The "Timekeeper" places an activation request on the noticeboard.

c) The "Housekeeper" starts any due activities so indicated.

d) When the task has been completed, the "Housekeeper" modifies the Diary table to indicate the time of next activation of that task.

Appendix 4

Publications Arising from this Research.

A4.1 Technical Papers

Support Systems for Total Quality

Barbara M Savage

Accepted for publication at the UK Systems Society Conference to be held at the University of Paisley, July 1993.

Abstract:

The strategy of Total Quality Management (TQM) states that every organisation activity contributes to the final quality of the product as perceived by the customer, and thus requires that the quality of all elements of organisational activity be monitored and improved. It is not sufficient for the quality system to focus only on the production cycle, because quality, as evidenced by customer satisfaction, may be affected by a wide range of factors, over and above the mainstream of production activities. Thus it may be seen that all data available in an organisation may have potential for informing the quality improvement process. Hence, the quality system must be provided with the means of accessing any of the data held by the various information systems extant in the organisation. Indeed, a case may be made for significant data links between organisations throughout the supply chain.

Quality monitoring activities, however they may be focused, generate large quantities of raw data which must be analysed to determine trends and identify weak points in the

process. They must be properly coordinated, with control being exercised over measurement methods and criteria. There is, therefore, a need for mechanisms to support the quality system by acquiring and storing data, and subsequently to provide a flexible access service to the data for analysis.

Whilst a number of quality support software products are currently available, none provides the flexibility or generality of data access required for true TQM. In addition, many of the present offerings tie the user organisation into particular quality assurance or improvement techniques. Thus a technique independent quality support system must be developed.

In this paper, a proposal for such a system is described and assessed against the needs of a particular company who acted as a test site. Finally, directions for future developments are examined.

Fresh Fruit Product Life Tracking

J Knight, B M Savage, G Emmanoulopoulos & J Puig Gomez

Expert Systems in Agriculture, International Federation for Automatic Control (IFAC) Workshop, Huangshan, China, 12-14 August 1992

Abstract:

This paper reports on the results of the ESPRIT project 5379 FRUIT (Fresh Fruit Product Life Tracking). The project FRUIT addresses the development and introduction of CIM technology into a particular sector of the agricultural industry. The research

within FRUIT is focused on the development of a product life tracking system for fresh citrus fruit, in particular oranges, from the packing house, during transportation to the marketplace up to, and including, the point of sale. The results of several aspects of the tracking system design are reported in this paper including the development of the life tracking system within a fruit packing house and of the sensors capable of detecting the gaseous and volatile emissions from oranges.

Fresh Product Life Tracking System

J Knight, B M Savage, C L Honeybourne, G Emmanoulopoulos & J Puig Gomez

In: O'Brien, C; MacConall, P and Van Puymbroeck, W (Eds); *Computer Integrated Manufacturing, Proceedings of the 8th CIM-Europe Annual Conference*, Birmingham, UK, Springer-Verlag, ISBN 3-540-19766-4 & 0-387-19766-4, 27-29 May 1992, pp 271-280

Abstract:

This paper reports on the results of ESPRIT project 5379 FRUIT (Fresh Fruit Product Life Tracking). The project FRUIT addresses the development and introduction of CIM technology into a particular sector of the agricultural industry. The research with FRUIT is focused on the development of a product life tracking system for fresh citrus fruit, in particular oranges, from the packing house, during transportation to the marketplace up to, and including, the point of sale. The results of several aspects of the tracking system design are reported in this paper including the development of the life tracking system within a fruit packing house and of the sensors capable of detecting the gaseous and volatile emissions from oranges.

Automating Quality Systems

J D T Tannock, R G Wort & B M Savage

Proceedings of the Institution of Mechanical Engineers, Part B: Engineering Manufacture, Volume 204, 1990, pp 231-236

Abstract:

This paper proposes a strategy for the automation and integration of quality systems for manufacture. It describes a systematic structured quality system design and improvement process, together with a comprehensive approach to automation in data collection and quality data management; within a framework - compatible with the themes of Total Quality Management - which a manufacturing company may use to automatic quality control operations.

Computerisation of Quality Information

B M Savage, C Hakes & J A G Knight

Computer Aids for Quality, 13th March 1990, Institution of Mechanical Engineers, London.

Abstract:

The adoption by manufacturing and process industry of Total Quality Management (TQM) techniques requires that the quality of all activities, within an organisation, be continually monitored and improved. For TQM to be implemented effectively in manufacturing and process industry, which is inevitably moving towards a Computer Integrated Manufacturing environment, requires an understanding of the necessary system architecture and appropriate distributed systems and interfaces.

To develop distributed systems for TQM, the fundamental problems of; treatment of new data types; the collection, storage, processing and retrieval of quality information; the design of system architecture and the definition of distributed systems and interfaces for TQM; application of knowledge based systems in a distributed system for quality, have to be considered.

This paper outlines the requirements for computerisation of a total quality system for manufacturing industry and examines realisation of such a system.

Requirements for the Quality Database

Barbara M Savage & James D T Tannock

International Journal of Quality & Reliability Management, Volume 6, Number 6, 1989, pp 31-39

Abstract:

Quality control in a manufacturing organisation may be viewed as an information management system, the functions of which are the collection, processing, storage and presentation of quality information. In recent years, there have been indications that a trend towards flexible, small batch and low stock manufacturing has placed traditional paper-based quality control systems under strain, especially with regard to the speed with which information feedback can be provided to manufacturing and process planning decision maker,s thus limiting the speed of their responses to quality problems. Effective Total Quality Management requires not only concern for human factors themes and emphasis on company-wide quality improvement activities, but also

access to correct, timely and sufficient quality information.

Integrated Quality Systems

J D T Tannock, R G Wort, B M Savage & P Jervis

Proceedings of the ACME Grant Holders Conference, Loughborough, September 1989.

Abstract:

This paper describes a strategy for the automation and integration of quality systems for manufacture. It proposes the use of a systematic, comprehensive approach to automation in quality data collection and management, within a framework - compatible with the themes of Total Quality Management (TQM) - which a manufacturing company may use to automate quality control operations.

Defining Requirements for the Quality Database

Barbara M Savage & James D T Tannock

In: Worthington, B (Ed); *Advances in Manufacturing Technology III, Proceedings of the Fourth National Conference on Production Research*, Sheffield, UK, Kogan Page, ISBN 1-85091-704-3, September 1988, pp 40-44

Abstract:

The importance of the quality database to advanced manufacturing is described, and a database structure is suggested, consisting of a distributed relational database, with a central database interfaced to automatic and computer aided quality monitoring systems. consideration is given to the importance of defining criteria for the selection of a suitable software development tool, given the need for good functionality, coupled with

portability across a range of hardware.

The development of functional requirements for the proposed system is seen as a multi-stage process. The existing quality data management system is examined and is then used as the basis for a 'wish list' or required functions for the proposed quality database. The specification process is discussed, and the care functions of the quality database are identified and described. Compatibility with future developments towards computer integrated manufacture is an important factor, and data exchange requirements with other computer systems are considered.

A4.2 Research Proposals

In addition to the papers listed above, a number of collaborative research proposals have arisen from the work described herein. These are listed below.

In response to the EC Esprit Call - January 1990

TASIC - Product Life Tracking for Application Specific Integrated Chips

Bristol Polytechnic in partnership with James Martin Associates (B), Thomson Composants Micro-ondes (F), Altcatel Espace (F), ESA/ESTEC (NL), IWF Berlin (D), VIF-INFO (F), Eurosoft (F) and Transfer Technology (UK)

Total cost of proposal: 13,909,251 ECU

Result: not funded.

FRUIT - Fresh Fruit Life Tracking

Bristol Polytechnic in partnership with Fomesa (E), Robotec (UK), Syntax Factory Automation (I) and Trademco (GR)

Result: funded for 27 months with a budget of 1,000,000 ECU as Esprit project number 5379.

In response to the EC Esprit Call - October 1991

FRESH - Information Technology Support for Growing and Trading FRESH Produce at Optimum Quality

Bristol Polytechnic in partnership with Fomesa (E), Robotec (UK), Syntax Factory Automation (I) and Trademco (GR)

Total cost of proposal: 5,665,000 ECU

Result: not funded.

MARQUIS - Manufacturing Related Quality Information System

Bristol Polytechnic in partnership with Systemhaus Industrie (D) including AEG and MBB, Syntax Factory Automation (I), IAO (D) and IWF/IAP (D)

Total cost of proposal: 12,362,250 ECU.

Result: not funded.

In response to a call on Agriculture and Agro-Industries from EC DG VI, DG XII and DG XIV - January 1992

Better Produce for Consumers

Bristol Polytechnic in partnership with Fomesa (E), Robotec (UK), Syntax Factory Automation (I) and Trademco (GR)

Total cost of proposal: 4,372,084 ECU.

Result: not funded.

In response to EC Brite/Euram call - April 1992

LEQUIC - Lean Efficient Quality Information Chain

Bristol Polytechnic in partnership with AEG (D), Syntax Factory Automation (I), IAP (D) and IAO (D)

Total cost of proposal: 4,997,918 ECU

Result: Graded B, but not funded.

In response to a call on Agriculture and Agro-Industries from EC DG VI, DG XII and DG XIV - October 1992

EQUIP - Enhanced Fruit Quality Assurance and Prediction

Bristol Polytechnic in partnership with Fomesa (E), Robotec (UK), Syntax Factory Automation (I) and Trademco (GR)

Total cost of proposal: 4,823,135 ECU.

Result: not yet known.

In response to EC Brite/Euram call - February 1993

Three proposals are in preparation. These are for a Concerted Action in Computer Support for Quality, for a Focused Fundamental Research project concerned with quality data handling in different industrial sectors, and finally a reworked version of LEQUIC.

Appendix 5

The IQS Prototype

A5.1 The Menus

The prototype IQS was implemented using the Oracle RDMBS and had a menu driven user interface. Some of the menus are shown below, along with an indication of the action taken in response to selection of each menu item.

Quality Project Demonstration System

1. Data Entry & Update Menu	2. Reports on Batch Status
3. Inspection Results Report Menu	4. Customer Complaints
5. Calibration Records	6. Staff Records Menu
7. Vendor Records Menu	0. Exit

Enter your choice & press RETURN:

Actions:

1. Call block IUMENU
2. Calls block REPMENU
3. Calls block INRES
4. Calls block COMPLAINTMENU
5. Calls form CALIBRATE
6. Calls block STAFFM
7. Calls block VENMENU

Data Entry & Update Menu

1. Product Details
2. Batch Details
3. W/O Schedule
4. Part Inspection Details
5. Inspection Spec Details
6. Inspection Stations
0. Return to main mune

Enter your choice & press RETURN:

Actions:

1. Calls form PRODUCTS which accesses table PRODUCTS
2. Calls form BATDET which accessed table BATCHES and looks up PRODUCTS via PART_NO
3. Calls form WOSCHED whcih accesses table SCHEDULED_WO
4. Calls form PINSP which accesses table PART_INSP
5. Calls form INSPEC which accesses tables INSP_HEAD & SPEC_DETAIL linked by INSP_ID; also looks up ISTATION_LOOKUP via ISTATION_TYPE
6. Calls for STATIONS which accesses table ISTATION_LOOKUP

Reports on Batch Status

1. New Batches
2. Continuing Batches
3. Held Batches
4. Finished Batches
0. Return to main manu

Enter your choice & press RETURN:

Actions:

1. Executes form level trigger NEWREP
2. Executes form level trigger CONTREP
3. Executes form level trigger HELDREP
4. Executes form level trigger FINREP

All of these reports access tables BATCHES & PRODUCTS linked by PART_NO

Customer Complaints

1. Enter/Update Complaints
2. Complaints Awaiting Investigation
3. Finalised Complaints
4. Summary by Part Number
5. Summary by Failure Mode

0. Return to main menu

Enter your choice & press RETURN:

Actions:

1. Calls form COMPLAINTS
2. Executes form level trigger AWAIT
3. Executes form level trigger FINISHEDCOPM
4. Executes form level trigger PARTREP
5. Executes form level trigger FAILCOMP

All options access tables COMPLAINTS & MODE_LOOKUP linked by FAILMODE.

Option 1 also uses table PRODUCTS for lookup via PART_NO

Staff Records Menu

1. Enter Staff Name & Dept
2. Enter Training Records & Course Details
3. Training & Course Report Menu
4. Safety Records Menu
0. Return to main menu

Enter your choice & press RETURN:

Actions:

1. Calls form STAFF
2. Calls form TRAINING
3. Calls block TRAINR
4. Calls block SAFETY

A5.2 The Reports

The prototype produced a wide range of standard reports, a selection of which are should below, along with the SQL code used to produce them.

Tue Oct 10 page

Details of Continuing Batches

W/O No	Part No	Product description	Quantity Required	Week No	Year
01901151	75875-101-16	BergStik Header Jumbo Straight	2,300	3	89
01903447	65307-001	Polarization Plug	7,050	4	89
01902110	76350-303-72	BergStik Header Right-Angle 2 row	1,600	4	89
01903401	67027-002	Latches	4,700	5	89
01902111	76350-303-72	BergStik Header Right-Angle 2 row	6,600	5	89
01904490	76345-203-72	BergStik Header Right-Angle 2 row - wide	10,500	5	89

```
set pagesize 20;
ttitle 'Details of Continuing Batches';
column product_name heading 'Product description' format a25 word_wrapped;
column wo_no heading 'W/O No' format a9;
column part_no heading 'Part No';
column qty_reqd heading 'Quantity|Required' format 9999,999;
column prodweek_no heading 'Week|No';
column year heading 'Year' format a4;
select wo_no,scheduled_wo.part_no,products.product_name,qty_reqd,
prodweek_no, year
from scheduled_wo,products
where status = 'c' and scheduled_wo.part_no = products.part_no
order by year, prodweek_no;
```

ue Oct 10 pag

Details of Finished Batches

Work Order	Part No	Product description	Quantity Required	Week No	Year
1901147	75844-122-72	BergStik Header Straight Double Row	4,500	45	88
1901148	76350-803-72	BergStik Header Right-Angle 2 row	7,500	45	88
1901149	75245-505		8,900	46	88
1901150	75844-122-72	BergStik Header Straight Double Row	1,800	50	88
1905143	75875-101-16	BergStik Header Jumbo Straight	3,500	1	89
1902241	65921-002	Strain Relief	3,800	3	89

6 records selected.

```
set pagesize 40;
set linesize 80;
ttitle 'Details of Finished Batches';
column product_name heading 'Product description' format a25 word_wrapped;
column wo_no heading 'Work|Order' format a9;
column part_no heading 'Part No';
column qty_reqd heading 'Quantity|Required' format 9999,999;
column prodweek_no heading 'Week|No';
column year heading 'Year' format a4;
select wo_no, scheduled_wo.part_no, products.product_name, qty_reqd,
prodweek_no, year
from scheduled_wo,products
where status = 'f' and scheduled_wo.part_no = products.part_no
order by year, prodweek_no;
```

e Oct 10

Training Courses Completed

me	Department	COURSE_NAME
OGGS J T	ENGINEERING	Elements of PC Usage
RRISON S	QUALITY	Elements of PC Usage
NG G E	QUALITY	Elements of PC Usage Advanced PC techniques - Word Processing Further PC techniques - Word Processing
RDOE D E R	QUALITY	Elements of PC Usage
ERNON V W	QUALITY	Elements of PC Usage Further PC techniques - Word Processing Advanced PC techniques - Word Processing

records selected.

```
et pagesize 20;
reak on staff_name on dept skip 1;
itle 'Training Courses Completed';
olumn staff_name heading 'Name';
olumn dept heading 'Department';
olumn course_name heading 'Course Title';
elect training.staff_name, dept, course_name
rom staff, training, courses
here (staff.staff_name = training.staff_name)
nd   (training.course_ref = courses.course_ref)
nd   (course_done = 'd')
rder by staff.staff_name, dept;
```

```
ye Oct 10                                                              page

                              Outstanding Courses

ourse                                          Course
itle                                           Ref       Trainee
---------------------------------------------- --------- --------------------
urther PC techniques - Spreadsheets            aa/pc/2   BLOGGS J T
                                               aa/pc/2   GEORGE B F
                                               aa/pc/2   PARDOE D E R

urther PC techniques - Word Processing         aa/pc/3   BLOGGS J T
                                               aa/pc/3   GEORGE B F
```

```
set pagesize 20;
break on course_name skip 1;
ttitle 'Outstanding Courses';
column course_name heading 'Course|Title';
column course_ref heading 'Course|Ref';
column staff_name heading 'Trainee';
select course_name, courses.course_ref, staff_name
from   training, courses
where (training.course_ref = courses.course_ref)
and    (course_done = 'r')
order by course_name, staff_name
```

ed Oct 11

Courses Available

ourse itle	Course Ref	No Days	Course Content
dvanced PC techniques - ord Processing	aa/pc/4	2	Advanced word processing; headers. footers & fancy page layouts; spec types (super & subscripts)
lements of PC Usage	aa/pc/1	3	starting the machine; loading soft from floppy disc; doing backups
urther PC techniques - preadsheets	aa/pc/2	1	Setting up and using a simple spreadsheet
urther PC techniques - ord Processing	aa/pc/3	1	Elementary word processing

```
et pagesize 20;
reak on course_name skip 1;
title 'Courses Available';
olumn course_name heading 'Course|Title' format a25 word_wrapped;
olumn course_ref heading 'Course|Ref';
olumn duration heading 'No|Days' format 9999;
olumn course_content heading 'Course|Content' format a38 word_wrapped;
elect course_name, course_ref, duration, course_content
rom  courses
rder by course_name;
```

```
ue Oct 10                                                              pag
                        Complaints Awaiting Investigation

                                                          Quantity Date
ustomer Name          Complaint                             Faulty Received
--------------------- ------------------------------ ----------- ---------
 K HARRISON LTD       Plastic bodies deformed               500 19-MAY-89
ONES & JONES INC      Wrong part ordered                    500 28-MAY-89
ALINSKI BROTHERS      Products badly scratched             1570 01-JUN-89
MITH INDUSTRIES       Missing pins                           89 23-JUN-89
```

```
set pagesize 20;
set linesize 80;
ttitle 'Complaints Awaiting Investigation';
column cust_name heading 'Customer Name' format a20;
column comp_desc heading 'Complaint' format a30 word_wrapped;
column defect_qty heading 'Quantity|Faulty' format 9999999999;
column comp_recd heading 'Date|Received';
select cust_name, comp_desc, defect_qty, comp_recd
from complaints
where response_made is null
order by comp_recd;
```

Tue Oct 10

Customer Complaints - Summary of Modes of Failure

Fail Mode	Fault Description	Part Number	Value in M$
110	Lact of certificate	76350-303-72	.001
303	Wrong partnumber	75844-122-72	.004
		75875-101-16	.001
502	Functional	76350-303-72	.001
510	Slivers/chips/cracks/fractures/tools marks/scratches	75844-122-72	.001

```
lear breaks;
lear computes;
et pagesize 20;
et linesize 80;
reak on failmode on faultdescription skip 2;
em compute count of part_no on failmode;
itle 'Customer Complaints - Summary of Modes of Failure';
olumn failmode heading 'Fail|Mode' format a4;
olumn faultdescription heading 'Fault|Description' format a38 word_wrapped
olumn part_no heading 'Part|Number';
olumn defect_value$ heading 'Value|in M$';
elect complaints.failmode, faultdescription, part_no, defect_value$
rom complaints, mode_lookup
here complaints.failmode = mode_lookup.failmode
rder by complaints.failmode;
```

```
Oct  3                                                                  page
          Customer Complaints - Summary of Failures by Part No

er        Product                                    Fail Work            Value
          Name                                       Mode Order           in M$
--------- ------------------------------------------ ---- ------------ ----------
4-122-72  BergStik Header Straight Double Row        303  E1901147          .004
                                                     510  E1901154          .001
                                                     515  E1901150             0
5-101-16  BergStik Header Jumbo Straight             303  E1901151          .001
0-303-72  BergStik Header Right-Angle 2 row          502  E1902110          .001
                                                     110  E1902111          .001

cords selected.


lear breaks;
et pagesize 20;
et linesize 80;
break on part_no on product_name;
ttitle 'Customer Complaints - Summary of Failures by Part No';
olumn part_no heading 'Part|Number';
olumn product_name heading 'Product|Name' format a35 word_wrapped;
olumn failmode heading 'Fail|Mode' format a4;
olumn wo_no heading 'Work|Order';
olumn defect_value$ heading 'Value|in M$';
elect complaints.part_no, product_name, failmode, wo_no, defect_value$
rom complaints, products
here complaints.part_no = products.part_no
rder by complaints.part_no;
```

A5.3 The Flunkeys

The Flunkeys were implemented in C with embedded SQL. This was compiled using a special preprocessor provided by Oracle. Some typical contents for the Noticeboard and the Housekeeper's Reference Table are shown below, as are the code for the Housekeeper and one of the other flunkeys.

A5.3.1 The Noticeboard

```
SQL> select * from noticeboard;

NO QDAAS I NOTICE
-- ----- - ------------------------------------
ip cail   c week 9
eb autol v batch end report E1590001
iw auto2 v E1592012
```

A5.3.2 The Housekeeper's Reference Table

```
SQL> select * from houseref;

NO ACTION                      FLUNKEY    DO_NOTHING NE
-- ------------------------------ ---------- ---------- --
ip Request for active Ispecs   flunkey             0
iw Request for specific Ispec  flunkey             0
eb Batch end report delivered  porter              1 zz
zz Wait for flunkey to complete                    0
cc Call Cleaner                cleaner             0 cn
cn Wait for Cleaner to erase                       0

6 records selected.
```

A5.3.3 The Housekeeper

```
/* Housekeeper daemon */
/* Barbara M Savage, May 1989 */

#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <memory.h>

EXEC SQL BEGIN DECLARE SECTION;

  VARCHAR uid[20];
  VARCHAR pwd[20];
  VARCHAR noticetype[2], qdaas_id[5], istation_key[1], notice[35];
  VARCHAR notetype[2], action[30], flunkey[10], nextnotice[2];
      int do_nothing;

EXEC SQL END DECLARE SECTION;
EXEC SQL INCLUDE sqlca.h;

static unsigned int ret_value;

/********** catch_oracle_error **********/

catch_oracle_error()

{
  if (sqlca.sqlcode > 0)
     printf("%.70s\n",sqlca.sqlerrm.sqlerrmc);
}

/********** printvc **********/

printvc(len, arr)

int len;
char arr[];
{
  int i;
  for (i=0; i<len; i++)
      putchar(arr[i]);
  putchar(' ');
}
```

```
/********** print_rows **********/

print_rows(n)

long n;
{
  long j;

  printf("\nNotice\t\t\t\tType\n");
  printvc(notice.len, notice.arr);
  for (j=notice.len; j<35; j++)
      putchar(' ');
  printvc(noticetype.len, noticetype.arr);
  printf("\n");
  return;
}

/********** check_noticeboard **********/

check_noticeboard()

{
  long num_ret;

  EXEC SQL DECLARE C1 CURSOR FOR
       SELECT noticetype, notice, qdaas_id, istation_key
       FROM noticeboard;
  EXEC SQL OPEN C1;
  EXEC SQL WHENEVER NOT FOUND GOTO endloop;
  num_ret = 0;
  while(1)
      {
      EXEC SQL FETCH C1
           INTO :noticetype, :notice, :qdaas_id, istation_key;
      print_rows(sqlca.sqlerrd[2] - num_ret);
      num_ret = sqlca.sqlerrd[2];
      analyse();
      printf("After analyse\n");
      }
endloop:
  printf("Endloop for C1\n");
/*
  if (sqlca.sqlerrd[2] - num_ret > 0)
      {
      print_rows(sqlca.sqlerrd[2] - num_ret);
      analyse();
      }
*/
}
```

```
/********** analyse **********/

analyse()

{
  int notfound;
  int pid;
  char *path;

  EXEC SQL DECLARE C2 CURSOR FOR
       SELECT noticetype, action, flunkey, do_nothing, nextnotice
       FROM houseref;
  EXEC SQL OPEN C2;
  EXEC SQL WHENEVER NOT FOUND GOTO noaction;
  while(notfound)
    {
    EXEC SQL FETCH C2
         INTO :notetype, :action, :flunkey, do_nothing, :nextnotice
    action.arr[action.len] = '\0';
    if (strcmp(notetype.arr,noticetype.arr) == 0)
       notfound = 0;
    }
  printvc(action.len,action.arr);
  printf("\n");
  EXEC SQL CLOSE C2;
  if (do_nothing != 0)
     {
     if ((pid = fork()) == 0)
        {
        flunkey.arr[flunkey.len] = '\0';
        strcpy(path,"/users/barbara/cprogs/");
        strncat(path, flunkey.arr, flunkey.len);
        EXEC SQL UPDATE noticeboard
             SET noticetype = :nextnotice
             WHERE CURRENT OF C1;
        execl(path,0);
        }
     }
  else
     printf("No action required\n");
  return;
noaction:
  printf("Unknown type of notice\n");
  EXEC SQL CLOSE C2;
  return;
}
```

```
/********** start_oracle **********/

char *start_oracle()

{
  strcpy(uid.arr,"barbara");
  uid.len = strlen(uid.arr);
  strcpy(pwd.arr,"martin");
  pwd.len = strlen(pwd.arr);
  EXEC SQL CONNECT :uid IDENTIFIED BY :pwd;
  catch_oracle_error();
  printf("Housekeeper logged onto oracle\n");
}

/********** stop_oracle **********/

char *stop_oracle ()

{
  EXEC SQL COMMIT WORK RELEASE;
  catch_oracle_error();
  printf("logged off oracle\nHousekeeper stopped\n");
}

/********** main **********/

main ()

{
  printf("Housekeeper running\n");
  start_oracle();
  check_noticeboard();
  stop_oracle();
  exit();
}
```

A5.3.4 The Porter

```
/* Porter flunkey */
/* Barbara M Savage, June 1989 */

#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <memory.h>

EXEC SQL BEGIN DECLARE SECTION;

 VARCHAR uid[20];
 VARCHAR pwd[20];
 VARCHAR noticetype[2], qdaas_id[5], istation_key[1],
         notice[35];
 VARCHAR ntype[2], action[30];
 VARCHAR wo_no[12], insp_id[4], machine_no[4];
     int no_charac, total_no_defective;
 VARCHAR istation_type[6], message[80];
     int isequence, no_defective;
   float cp, mean, sd;

EXEC SQL END DECLARE SECTION;
EXEC SQL INCLUDE sqlca.h;

/********** catch_oracle_error **********/

catch_oracle_error()


 if (sqlca.sqlcode > 0)
    printf("%.70s\n",sqlca.sqlerrm.sqlerrmc);


/********** transfer **********/

transfer()


 EXEC SQL DECLARE P1 CURSOR FOR
      SELECT wo_no, insp_id, machine_no, no_charac, total_no_defectiv
             istation_type, message
      FROM batch_head_temp;
 EXEC SQL OPEN P1;
 EXEC SQL WHENEVER NOT FOUND GOTO endheaders;
```

```
while(1)
  {
  printf("Accessing batch headers\n");
  EXEC SQL FETCH P1
       INTO :wo_no, :insp_id, :machine_no, :no_charac, :total_no_defect
            :istation_type, :message;
  EXEC SQL INSERT INTO batch_head_master
       VALUES (:wo_no, :insp_id, :machine_no, :no_charac,
           :total_no_defective, :istation_type, :message);
  catch_oracle_error();
  EXEC SQL COMMIT WORK;
  }

headers:
EXEC SQL CLOSE P1;
EXEC SQL DECLARE P2 CURSOR FOR
    SELECT wo_no, insp_id, machine_no, isequence, no_defective, cp, mea
    FROM batch_detail_temp;
EXEC SQL OPEN P2;
EXEC SQL WHENEVER NOT FOUND GOTO endloop;

while(1)
  {
  printf("Accessing batch details\n");
  EXEC SQL FETCH P2
       INTO :wo_no, :insp_id, :machine_no, :isequence, :no_defective,
            :cp, :mean, :sd;
  EXEC SQL INSERT INTO batch_detail_master
       VALUES (:wo_no, :insp_id, :machine_no, :isequence,
           :no_defective, :cp, :mean, :sd);
  catch_oracle_error();
  EXEC SQL COMMIT WORK;
  }

loop:
EXEC SQL CLOSE P1;
EXEC SQL CLOSE P2;


******** update_notice **********/

date_notice()


EXEC SQL UPDATE noticeboard
    SET noticetype = "cc"
    WHERE (noticetype = :noticetype) and (qdaas_id = :qdaas_id);
loop:
printf("Error in updating noticeboard\n");
```

```
********* start_oracle **********/

r *start_oracle()


trcpy(uid.arr,"barbara");
id.len = strlen(uid.arr);
trcpy(pwd.arr,"martin");
wd.len = strlen(pwd.arr);

XEC SQL CONNECT :uid IDENTIFIED BY :pwd;

atch_oracle_error();
rintf("Porter logged onto oracle\n");


********* stop_oracle **********/

r *stop_oracle ()


XEC SQL COMMIT WORK RELEASE;

atch_oracle_error();
rintf("Porter logged off oracle & stopped\n");


********* main **********/

n ()


rintf("Porter running\n");
tart_oracle();
ransfer();
top_oracle();
xit();
```

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